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GROUND-WATER SUPPLIES FOR INDUSTRIAL AND URBAN DEVELOPMENT IN ANNE ARUNDEL COUNTY

By Frederick K. Mack

With a Section on the

CHEMICAL CHARACTER OF THE WATER

By Claire A. Richardson

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GROUND-WATER SUPPLIES FOR INDUSTRIAL AND URBAN DEVELOPMENT IN ANNE ARUNDEL COUNTY

BY

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ABSTRACT

This report is an appraisal of ground-water resources in a rapidly growing area in the Maryland coastal plain. It was prepared to guide County and State planners in effectively locating new water-using industries, commercial establishments, and public water supplies.

Bounded on the north by Baltimore City, on the east by the Chesapeake Bay, and on the west by the Patuxent River, Anne Arundel County includes an area of 417 square miles of land surface and is situated on a part of the Atlantic Coastal Plain which is adjacent to the Piedmont province. About half of the land surface is less than 100 feet above sea level and less than one square mile is more than 300 feet above sea level. Estuaries of the Chesapeake Bay extend inland to the center of the County. The climate is humid and temperate with a mean annual temperature of 56°F and an average precipitation of about 44 inches.

The County is underlain by a wedge-shaped mass of unconsolidated coastal plain sediments of Cretaceous, Tertiary, and Quaternary age which overlie much older consolidated crystalline rocks. The wedge of sediments is less than 50 feet thick in the northwestern part of the County but thickens to about 2,000 feet in the southeastern part of the County. The five major aquifers of the County—the Patuxent, the Patapsco, the Raritan, the Magothy, and the Aquia Formations—dip gently toward the southeast.

An average of 20 mgd (million gallons per day) of water were used in Anne Arundel County in 1960. About 70 per cent of that quantity was from ground-water sources within the County and 30 per cent was from surface-water sources.

The investigation shows that approximately 80 mgd is available from the artesian aquifers, and that an additional 50 mgd may be available from water-table aquifers. Thus, the limit of water available is on the order of 130 mgd.

A systematic appraisal of the ground water available from each of ten localities in the County shows that details of ground-water conditions vary from

place to place. The thinness of the unconsolidated sediments in the northwestern part of the County limits the amount of drawdown available and thus the amount of water available from individual wells. Geologic conditions will permit the removal of large quantities of water from the eastern part of the County, but overexploitation of the ground water there would lower hydraulic heads in the aquifers and eventually induce contamination by brackish water from the Chesapeake Bay or its estuaries.

INTRODUCTION

Purpose of Investigation

It has long been known that Anne Arundel County is rich in ground-water resources. Many users had a vague belief that these resources were unlimited. However, in recent years, the increasing demands for water in many parts of the area have not always been met easily. County and State officials, viewing this fact and the fact that water demands will probably double in the next 20 years, realized that detailed ground-water information must be readily available in order to properly utilize this resource. In order to furnish the County Planners with a guide in locating new water-using industries, commercial establishments, and public water supplies, this study was undertaken to appraise and evaluate the ground-water resources of the County.

Methods of Investigation

The report is based on data collected during the course of two earlier studies describing the ground-water resources of Anne Arundel County (Brookhart, 1949) and (Otton, 1955) and on more detailed data and current information collected for this report.

The data were obtained by the following procedures: 1) collection of information on the location, depth, diameter, yield, and other pertinent features of approximately 1,450 wells and test holes; 2) field examination of outcrops of surficial deposits and laboratory examination of drill cuttings and well logs, to supplement existing geologic information; 3) collection and analysis of 203 water samples from the aquifers for the determination of chemical characteristics; 4) measurement of the water levels in 16 observation wells to determine the magnitude of fluctuations due to natural causes and to pumping; 5) collection and analysis of 50 samples of water-bearing formations to determine physical properties such as porosity and the sizes of constituent particles; 6) test pumping of wells at 32 sites to determine the coefficients of transmissibility and storage of the aquifers.

The basic data used in the preparation of this report are on file in the ground-water office in Baltimore.

Acknowledgments

The authors wish to acknowledge the assistance rendered by the cooperation of well drillers, well owners, and Federal, State, County, and City agencies. The Layne-Atlantic Co. and H. H. Bunker and Sons, Inc. were especially helpful in providing well-construction data and other well information. The Anne Arundel County Sanitary Commission provided assistance in aquifer tests at their well fields. Officials and employees of the Naval Academy aided in aquifer tests at the Academy. Appreciation is expressed for information on ground-water conditions at Belair provided by Leggette, Brashears and Graham, Inc. The project was carried out under the immediate supervision of E. G. Otton, district geologist of the U. S. Geological Survey.

Location and Extent of Area

Anne Arundel County is in the central part of Maryland (fig. 1). Its northern boundary is adjacent to the City of Baltimore and its western boundary is within 15 miles of Washington. The County extends 36 miles in the north-south direction and about 22 miles in an east-west direction. It includes an area of 417 square miles of land and 41 square miles of water. This area includes estuaries sheltered by headlands but excludes the Chesapeake Bay proper (Batschelet, 1942, p. 10). Annapolis, the capital of Maryland and the seat of Anne Arundel County, is located in the east central part of the County.

Climate

Anne Arundel County lies in the humid temperate climatic belt of the eastern part of the United States. It has warm summers and not extremely cold winters.

Precipitation and temperature data for Annapolis, based on over 88 years of record, are shown on figure 2. The mean annual precipitation is about 44 inches, but the amount and distribution of precipitation differ somewhat from year to year. The lowest annual precipitation was 21.16 inches in 1930, and the highest was 66.6 inches in 1907. Thus the precipitation during the wettest year was more than 3 times greater than that of the driest year. Although no particular month or season is exceptionally wet or dry, precipitation for individual months is extremely variable and unpredictable. Rainfall in August 1943 was only 0.19 inch, whereas in August 1867 it was 14.5 inches. An average of 107 days per year have 0.01 inch or more of precipitation. The average annual snowfall is about 21 inches.

Figure 2 shows that the minimum temperature was −6°F and the maximum was 106°F. Temperatures generally range between 35°F and 77°F. The average annual temperature is about 56°F. The highest annual temperature was 59.4°F in 1954 and the lowest was 51.3°F in 1856.

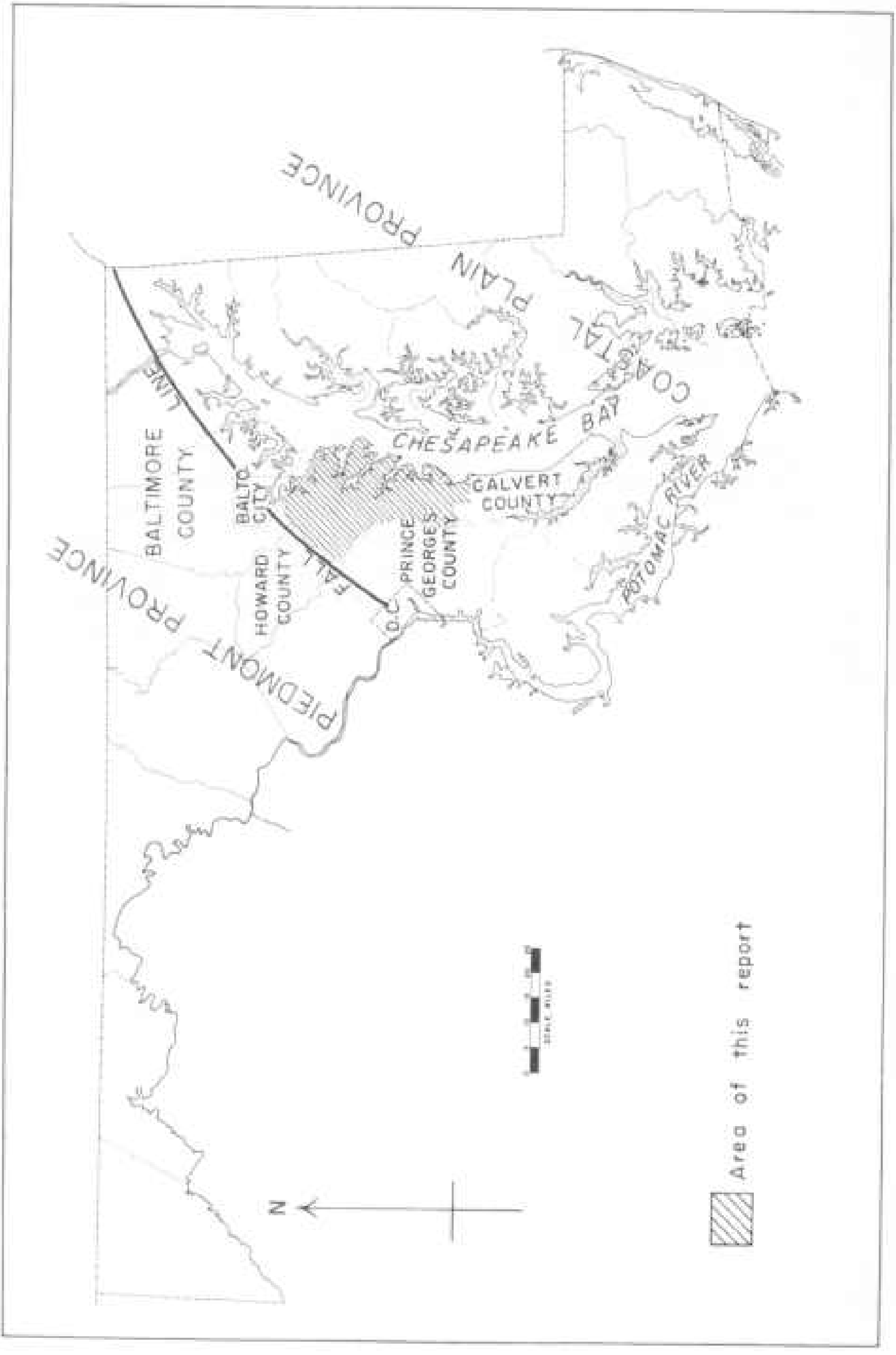

FIGURE 1. Map of Maryland Showing Location of Anne Arundel County

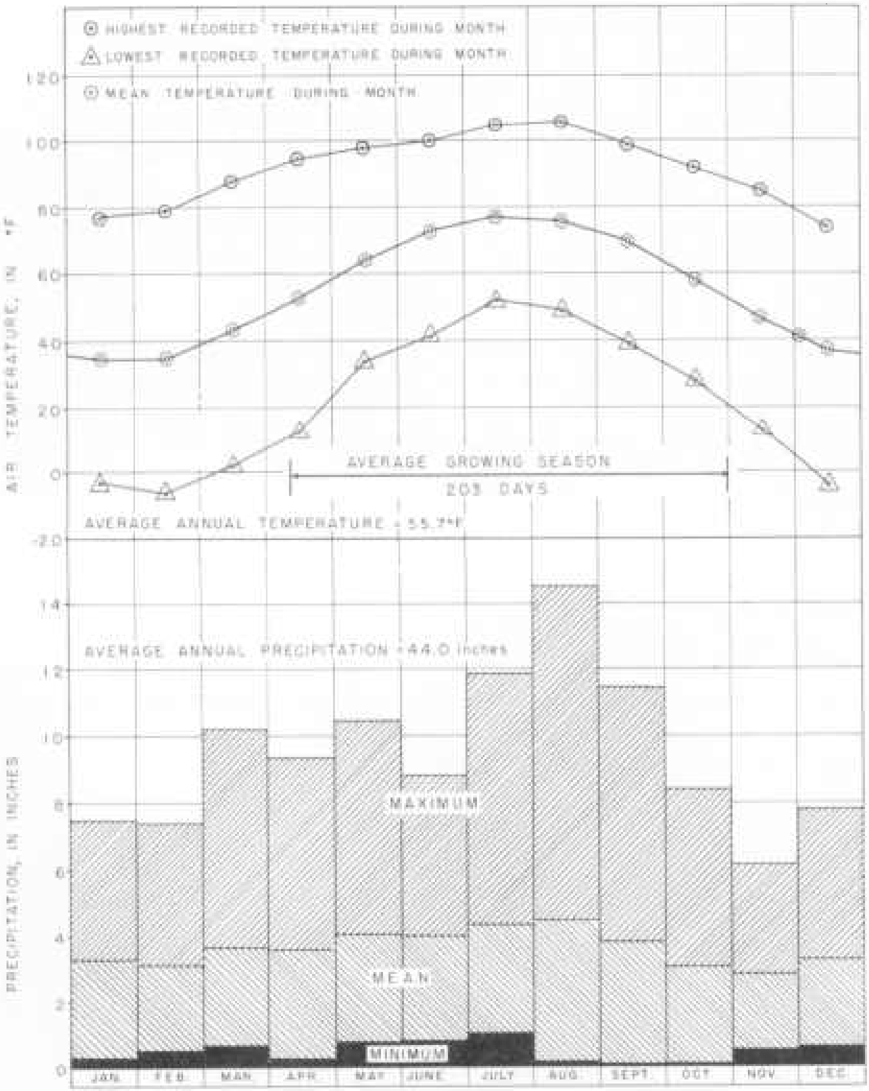

FIGURE 2. Graphs Showing Monthly Air Temperature and Precipitation at Annapolis

Surface Features

Anne Arundel County is entirely within the Coastal Plain physiographic province. Its northwestern boundary is in the fall zone with the Piedmont province just west of the County line (fig. 1).

The eastern half of the County consists of a series of peninsulas separated by estuaries of Chesapeake Bay. Some of the estuaries extend inland more than half the width of the County. Although extensive, they are shallow, commonly less than 20 feet deep. Some of the peninsulas are flat and low-lying with irregular shorelines. However, precipitous escarpments are common along the Severn River, the South River, and in places in the southern part of the County—as in the vicinity of Herring Bay. The highest part of the County is about 2 miles east of Laurel and is about 310 feet in altitude. From this high, the land surface slopes gently toward the river or bay boundaries of the County.

Population

The population of Anne Arundel County began to increase rapidly in the decade between 1940 and 1950 (fig. 3). The upward trend established in those years continued to 1960 when the population was about 206,000. The rapid population increase is expected to continue at least until 1980. The increase, however, is not expected to be uniformly distributed throughout the County; most of the increase has been and will continue to be in the northern part. Planning officials estimate that areas in the southern part of the County, which were relatively sparsely populated in 1960, will undergo only a 1.7-fold increase in the period 1960–1980, whereas the northern part of the County, already densely populated in 1960, will undergo a 2.5-fold increase.

The increase in population is attributed mainly to the movement of industrial and commercial establishments into the County with accompanying needs for workers and the development of suburban residential areas for workers employed in Baltimore and Washington.

WATER USE

In 1960, water-supply systems, excluding farm ponds, in Anne Arundel County supplied an average of about 20 mgd of water. About 70 per cent of this

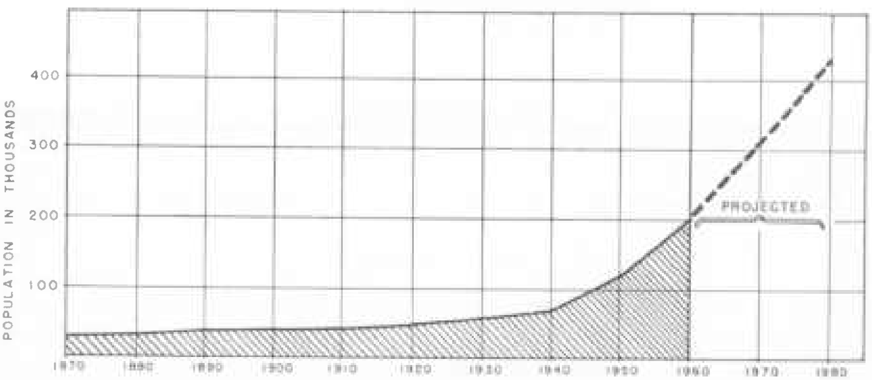

FIGURE 3. Graph Showing Population Trends in Anne Arundel County Since 1870

quantity was derived from ground-water sources within the County, 17 per cent was from surface-water sources within the County, and 13 per cent was from surface-water sources outside the County, chiefly water purchased from Baltimore City (Table 1).

Of about 14 mgd of ground water used, only 2.2 mgd was used by industries or large commercial establishments—much of it for air conditioning. The remaining approximately 12 mgd was used for domestic and farm purposes, for commercial use, and for use at military or governmental installations. A small quantity of ground water was used for irrigating farm crops but most of this use is seasonal; on an annual basis it is relatively unimportant.

Plate 1 shows the areas in and near Anne Arundel County where large quantities of ground water were being pumped in 1960. Some of the areas represent pumpage from two or more well fields. Table 2 shows the quantities of water pumped from each well field. Table 1 shows that about three-quarters of the total ground water used, was for public water supplies and commercial and industrial purposes. One-quarter of the ground water was used for small domestic supplies.

The average daily demand for water in Anne Arundel County in 1980 is ex-

TABLE 1

Use of Water in Anne Arundel County in 1960 by Source and Type of Use

Category	Source	Type of use	Average quantity used (mgd)
Ground water	Wells and springs	Public supply	8.6
		Industrial and commercial	1.5[1]
		Domestic and farm	3.6
	Total ground water		13.7
Surface water	Gunpowder Falls and Patapsco River	Public supply (Baltimore City public supply)	2.5
	Little Patuxent River	Military (Fort Meade)	2.6
	Dorsey Run and Little Patuxent River	Institutional supply (Maryland House of Correction)	.6
	Total surface water		5.7
Total water used			19.4
Water use per capita			94 (gpd)

[1] Self-supplied only; additional 0.7 mgd for industrial use obtained from public supply.

TABLE 2

Ground-Water Pumpage from Well Fields in Anne Arundel County in 1960

Well field	Average pumpage (mgd)
Annapolis, City of	2.40
Belvedere Heights[1]	.08
Crownsville State Hospital	.30
Dorsey Road (Glen Burnie)[1]	1.50
Gibson Island[1]	.07
Harundale (Glen Burnie)[1]	1.20
Kings Heights[1]	.10
National Plastic Products Company	1.30
Pines-on-Severn[1]	.05
Sawmill Creek (Glen Burnie)[1]	.70
Severna Park	.30
Sherwood Forest[2]	.07
U. S. Naval Academy	1.20
U. S. Naval Engineering Experiment Station	.60
Smaller public water supplies (13 combined)[2]	.14
Total	10.01

[1] Owned and operated by Anne Arundel County Sanitary Commission.
[2] Estimated on basis of number of service connections reported.

pected to be at least 40 mgd (Lyon, 1961). This estimate is based on the expectation that the population of the County will double by 1980. The northern part of the County, the area in which the rate of population growth will be greatest, will demand the major portion of the 40 mgd used in 1980.

GEOLOGY

The availability of ground water in Anne Arundel County is dependent on the local geology and the precipitation. Geologic conditions, to a large extent, control the amount of water that can be taken from a particular formation, the rate at which individual wells can be pumped, and the depth to which wells must be drilled.

Anne Arundel County is underlain by a wedge-shaped mass of unconsolidated sedimentary deposits, which overlie older consolidated crystalline rocks of Precambrian or Early Cambrian age. The unconsolidated deposits are stratified layers of sand, gravel, silt, and clay. The sand and gravel strata comprise the major water-bearing rocks.

The ancient crystalline rocks consist of gabbro, diorite, and other igneous and metamorphic rocks. The surface of the crystalline rocks dips gently toward the southeast as far as Salisbury (60 miles southeast of Anne Arundel County) where the dip steepens greatly (Vokes, 1957, fig. 12, p. 46). Just north of the Howard County line these rocks crop out at the land surface at an altitude of

200 to 300 feet above sea level. At Belair, in northeastern Prince Georges County, they lie at a depth of about 1,050 feet below sea level (Pl. 2). Near Holland Point, in the southeastern part of the County, they may be nearly 2,000 feet below sea level. Because they are buried at great depth throughout most of the County, they are seldom penetrated by drilling. Almost no information is available regarding their character. They commonly grade from fresh hard rock into a layer of clayey, rotted rock. Few wells yield water from the crystalline rocks where they lie buried beneath the sediments. Locally, a few gallons per minute may be obtained from wells which tap a deeply buried crevice or fracture.

The unconsolidated deposits are usually easy to drill and, where exposed, are generally soft enough to be worked with a shovel. The wedge-shaped mass of unconsolidated deposits thins to a few tens of feet in the northwest and is probably 2,000 feet thick in the southeast. Because the layers of sand, silt, clay, and gravel composing these deposits crop out at the surface, they have been studied extensively, described in detail, and geologic names have been given to several distinct units in the County.

Plate 3 is a generalized geologic map showing the outcrop of the rock units. Plate 4, three geologic sections across the County, shows that: 1) the depth to crystalline rock increases progressively toward the southeast; 2) the unconsolidated layers lap upon one another and the youngest (uppermost) formations are exposed progressively to the east; and 3) the formations thicken to the east. Little information is available regarding the unconsolidated deposits at depths greater than 700 feet in the central and southern parts of the County.

Table 3 summarizes the thickness and character of the geologic units in the area.

Plates 5, 6, 7, and 8 are contour maps showing the altitudes of the tops of the major water-bearing formations in the County. These maps predict the approximate depth at which an aquifer may be encountered. For example, if one wishes to drill to the Patuxent Formation at a location transected by the −800-foot contour, one need only add 800 feet to the altitude of the land surface at the proposed well site. The sum approximates the depth of drilling required to penetrate to the top of the formation. The slope or dip of the aquifers varies; the deepest aquifer, the Patuxent Formation, dips 85 to 90 feet per mile throughout the area, whereas the Aquia Greensand, one of the overlying aquifers, dips southeastward 15 to 20 feet per mile.

HYDROLOGY

Water evaporated from the sea and land surface and water transpired by plants rises into the atmosphere as water vapor. This water vapor is carried by the winds to other areas. Under the right conditions the vapor forms clouds and eventually returns to the earth as precipitation. Some of the precipitation infiltrates into the rocks to become ground water. The continuous circulation

TABLE 3

Character and Thickness of Geologic Units in Anne Arundel County

System	Series	Group	Formation	Average thickness (feet)	Lithology	General character
Quaternary	Recent and Pleistocene			30		Sand, gravel, silt, and clay.
Tertiary	Miocene	Chesapeake	Calvert	130		Sandy clay and fine sand, fossiliferous; diatomaceous earth.
	Eocene	Pamunkey	Nanjemoy	110		Glauconitic sand with clayey layers. Basal part is red or gray clay. (Marlboro Clay).
			Aquia Greensand	120		Glauconitic, greenish to brown sand with indurated or "rock" layers in middle and basal parts.
			Monmouth and Matawan	100		Sandy clay and sand, dark-gray to black, with some glauconite. Basal part is lighter in color and less glauconitic.
			Magothy	50		Light gray to white sand and gravel with interbedded clay layers; contains pyrite and lignite.
			Raritan	100		Interbedded sand and clay with ironstone nodules; locally contains indurated layers.

Cretaceous	Upper Cretaceous	Potomac	Patapsco	350		Interbedded sand, clay, and sandy clay; color variegated but chiefly hues of red and yellow.
			Arundel Clay	125		Red, brown, and gray clay; in places contains ironstone nodules and plant remains.
	Lower Cretaceous		Patuxent	160		Chiefly gray and yellow sand with interbedded clay; kaolinized feldspar and lignite common. Locally clay layers predominate.
Precambrian or Early Cambrian				Unknown		Chiefly gneiss, granite, gabbro, metagabbro, quartz, diorite, and granitized schist.

of water from the land and sea to the sky and from the sky to the land and sea is known as the "hydrologic cycle". It explains in a general way the source and movement of water in the streams and in the ground. Thus the water available from the aquifers in Anne Arundel County is derived from precipitation. The distribution of precipitation may be quantitatively expressed by the hydrologic budget. The hydrologic budget may be expressed by the equation:

$$P = R_s + R_g + \Delta S + E$$

In which:

P = precipitation
R_s = stream runoff
R_g = ground-water discharge or underflow (to the sea)
ΔS = change in ground-water storage $\left\{\begin{matrix}\text{ground-water recharge} \\ \text{ground-water discharge}\end{matrix}\right]$
E = evapotranspiration

Precipitation and stream runoff are the factors in the hydrologic budget that can be most accurately determined. Ground-water discharge to the sea is difficult to evaluate, but may be on the order of a few per cent of the precipitation. Changes in ground-water storage may be evaluated to some degree where adequate ground-water level records are available. Evapotranspiration is the most difficult to measure accurately. It is usually computed as a residual after all the other factors have been determined.

Over a period of several years, the changes in ground-water storage (ΔS) will tend to be zero, although for one 2-year period Rasmussen and Andreasen (1959, p. 98) report that the change in ground-water storage in Beaverdam Creek basin near Salisbury, Maryland, was about 2 per cent. An average rate of evapotranspiration (E) for Anne Arundel County has not been determined, but the value of about 60 per cent of the precipitation used by Rasmussen and Andreasen probably is in the right order of magnitude.

The values assigned to the general hydrologic equation for Anne Arundel County are:

	Symbol	Percent	Inches of water per year	Million gal per sq mi per year	Million gal per day	
					Per sq mi	Entire county
Stream runoff	R_s	35	15	2.6	0.7	292
Ground-water discharged to the sea	R_g	5[1]	2	.3	.1	42
Change in ground-water storage	ΔS	0	0	.0	.0	0
Evapotranspiration	E	60	27	4.7	1.3	540
Precipitation	P	100	44	7.6	2.1	874

[1] Assumed on the basis of preliminary data.

Source and Movement of Ground Water

About 60 percent of the precipitation in Anne Arundel County returns to the atmosphere through evaporation and transpiration. Perhaps 40 to 50 percent infiltrates through the soil zone and reaches the zone of saturation. This water, temporarily at least, increases the ΔS, or ground-water storage component, of the hydrologic cycle. Among the factors determining the amount of water that is absorbed by the ground are the porosity and permeability of the surficial materials, the slope of the land, the amount and kind of vegetable cover, and the intensity and amount of precipitation. Rain falling at a slow, steady rate on dry, permeable, flat ground infiltrates more readily than rain falling at a rapid rate on a moist, steep, relatively impermeable ground.

An average of about 2.1 mgd of precipitation falls per square mile of outcrop area of the aquifers. Studies of the hydrologic budget by Rasmussen and Andreasen (1959, p. 98) indicate that approximately 50 percent of the precipitation, or about 1 mgd per square mile, eventually reaches the water table and that about 45 percent of the water reaching the water table is returned to the atmosphere by evapotranspiration. Thus, roughly about 0.5 mgd of water is available for withdrawal from the ground-water reservoirs for each square mile of outcrop of the water-bearing formations.

Once water reaches the zone of saturation it begins to move laterally under the influence of gravity toward points of discharge, such as springs, wells, streams, or the Chesapeake Bay. Water thus in transit is under either water-table or artesian conditions. Where water only partially fills a permeable bed, its surface is free to rise and fall. Such water is unconfined and is said to be under water-table conditions. Where the water completely fills a permeable bed that is overlain by a relatively impermeable bed, its surface is not free to rise and fall and the water is said to be under artesian conditions. Water under artesian conditions is under sufficient pressure to rise above the top of the bed in which it occurs, though not necessarily above the land surface.

A formation in the zone of saturation that is permeable enough to transmit water in usable quantities to wells or springs is called an *aquifer*. Areas in which aquifers are replenished are called recharge areas. Areas in which water is lost by natural seepage from aquifers are called discharge areas. Water may also be discharged from aquifers by means of slow leakage or movement upward or downward through semipervious or relatively impervious confining beds. Such beds or layers are called *aquicludes*.

The quantity of water stored in an aquifer depends on the *porosity* or percentage of the total volume that is occupied by pores and other openings. The rate at which water moves in aquifers and the readiness with which it may be withdrawn through wells or discharged by springs is controlled by the *permeability*.

The major sources for the ground water in the aquifers of Anne Arundel

County are: 1) precipitation within the County which directly recharges the aquifers; 2) subsurface flow into the County, derived from precipitation in other counties, chiefly adjacent Prince Georges, Howard, and Baltimore; and 3) infiltration into the aquifers from streams whose flow originates chiefly in the Piedmont. Such infiltration is possible only when normal ground-water gradients are reversed as a result of pumping and water enters the aquifers directly from surface streams. At present the quantity of water entering the aquifers from surface streamflow is negligible.

Precipitation within the County is the source of most of the ground water currently used. However, heavy pumping of the artesian aquifers near the County boundaries will cause water to move into the area from adjacent recharge areas. As may be seen in Plate 3, all of the water-bearing formations crop out in the County. Some of the water arriving as precipitation at the outcrop area of each of these formations percolates into the ground and moves toward points of discharge which are always points of lower hydraulic head. As Maryland is in the humid climatic belt, the aquifers are brim full and water is continually being discharged from them to supply the flow of the streams during periods of no overland runoff.

Much of the water in the deeper formations may have originally entered the ground in adjacent counties. Some of this water has been in transit a long time because its rate of movement through the sands and gravels is slow under the low natural head differentials which prevail.

Water is discharged from the aquifers by seepage in low-lying areas, by evapotranspiration, and by pumpage from wells. Seepage from the ground furnishes the water flowing from springs and in surface streams during prolonged periods of no rainfall. Ground-water runoff in the Beaverdam Creek Basin reportedly amounted to about 11 inches per year, or about 26 percent of the precipitation (Rasmussen and Andreason, 1959, p. 98). This rate is believed to be relatively high, but is in accord with the high rate of ground-water recharge. Of course, over a period of time ground-water discharge must equal recharge or the quantity in storage would change.

Pumpage from wells, a form of ground-water discharge which was insignificant in the ground-water regimen of the County in the year 1900, is rapidly becoming a factor of importance and will be a more important form of discharge by the year 2000. Plates 9 and 10, maps of the piezometric surfaces in the Patuxent and Patapsco Formations, show areas of piezometric depression which are the result of heavy ground-water discharge from wells ending in those formations in the northern part of the County and in the adjacent Baltimore industrial area. Plate 9 shows that the discharge from the Patuxent Formation in the Baltimore industrial area has caused lowering of water levels in this aquifer for several miles along the northern boundary of Anne Arundel County.

AVAILABILITY OF GROUND WATER

The geologic and climatic conditions in Anne Arundel County favor the availability of ground water. Ground water, if properly developed, will always be available in the County. Water removed from the ground at a reasonable rate is replaced by water from precipitation. If pumping is carried out at too high a rate in the eastern part of the County, however, some of the water pumped may be replaced by salty water from the Chesapeake Bay. Such a condition would result in serious deterioration of the quality of the water and render it unusable for most purposes, unless an economic means is found to remove or decrease its salinity.

The availability of water from each of the four major aquifers in Anne Arundel County has been estimated on the basis of data available in 1961. The availability is described in terms of (1) controlling factors, (2) specific aquifers, and (3) specific areas.

Controlling Factors

Factors which must be considered in estimating the amount of ground water available in the County are: a) precipitation and infiltration capacity of the soil and subsoil; b) transmissibility, permeability, and storage of the aquifers; c) hydraulic head and movement; d) hazard of intrusion of brackish water from the Chesapeake Bay and its tributaries.

Precipitation and Infiltration Capacity

One inch of precipitation on an area of 1 square mile provides 17.4 mg of water. With an average annual precipitation of about 44 inches the total precipitation on the 417 square miles of Anne Arundel County is about 320 billion gallons per year or an average of about 870 mgd. Probably less than half of this amount reaches the zone of saturation to become ground water, and not all of this ground water is readily available for use by man.

Infiltration rates for the soils of Anne Arundel County are not available. In the Beaverdam Creek Basin near Salisbury, Rasmussen and Andreason (1959, p. 98) estimated that approximately 50 percent of the precipitation arriving at the land surface reached the zone of saturation. However, the soils of that area have high infiltration capacities. Doubtless, many of the soils of Anne Arundel County have infiltration capacities equal to those of the Beaverdam Creek Basin, but many of the more clayey soils have lower infiltration capacities. Probably over the entire area of the County the soils are capable of absorbing somewhat less than half the precipitation.

Permeability, Transmissibility and Storage

Hydraulic permeability is the capacity of a material to transmit water. The coefficient of permeability (P_f) is defined, in Geological Survey units, as the rate of flow of water in gallons per day through a cross-sectional area of 1 square foot under a hydraulic gradient of 1 foot per foot at the prevailing temperature. The coefficient of transmissibility (T) is the rate of flow of water in gallons per day through a vertical section of the aquifer 1 foot wide extending the full saturated thickness of the aquifer under a hydraulic gradient of 1 foot per foot. The thickness of the aquifer in feet is commonly designated by the symbol (m). Thus, the coefficient of transmissibility may be written:

$$T = P_f m.$$

The coefficients of transmissibility, permeability, and storage for aquifers may be determined from pumping tests, laboratory analyses of earth materials, and by approximate means using specific-capacity data from wells. Figure 4 explains graphically the concepts involved in the coefficients of permeability and transmissibility. Because the transmissibility of a water-bearing formation directly affects the water levels in the formation, tests to determine coefficients of transmissibility were made by pumping selected wells for known periods of time at known rates of discharge and, where possible, observing the following effects: 1) the hydraulic interference occurring in the aquifer determined by measuring water levels in one or more observation wells; 2) the rate at which the water level in the pumped well recovered when pumping was stopped; 3) the drawdown in the pumping well. Data obtained from these tests were analyzed by methods developed by Theis (1935) and Cooper and Jacob (1946). The methods of analysis of aquifer tests make use of the Theis nonequilibrium formula and modifications of it. The use of the formula implies certain idealized assumptions which are never realized in nature. Nevertheless, the Theis equation has been found to be a useful device in quantitative ground-water studies.

Where pumping tests can not be made coefficients of transmissibility can be estimated by a system devised by E. C. Reed (Keech and Dreeszen, 1959, p. 37–38). In this method each lens or layer of the aquifer, as shown by well logs or drill-cuttings descriptions, is assigned a coefficient of permeability within a range as follows:

Material	Range in coefficient of permeability (gpd/sq ft)
Clay and silt	0–100
Sand, very fine, silty	100–300
Sand, fine to medium	300–400
Sand, medium	400–600
Sand, medium to coarse	600–800
Sand, coarse	800–900
Sand, very coarse	900–1000
Sand and gravel	1000–2000

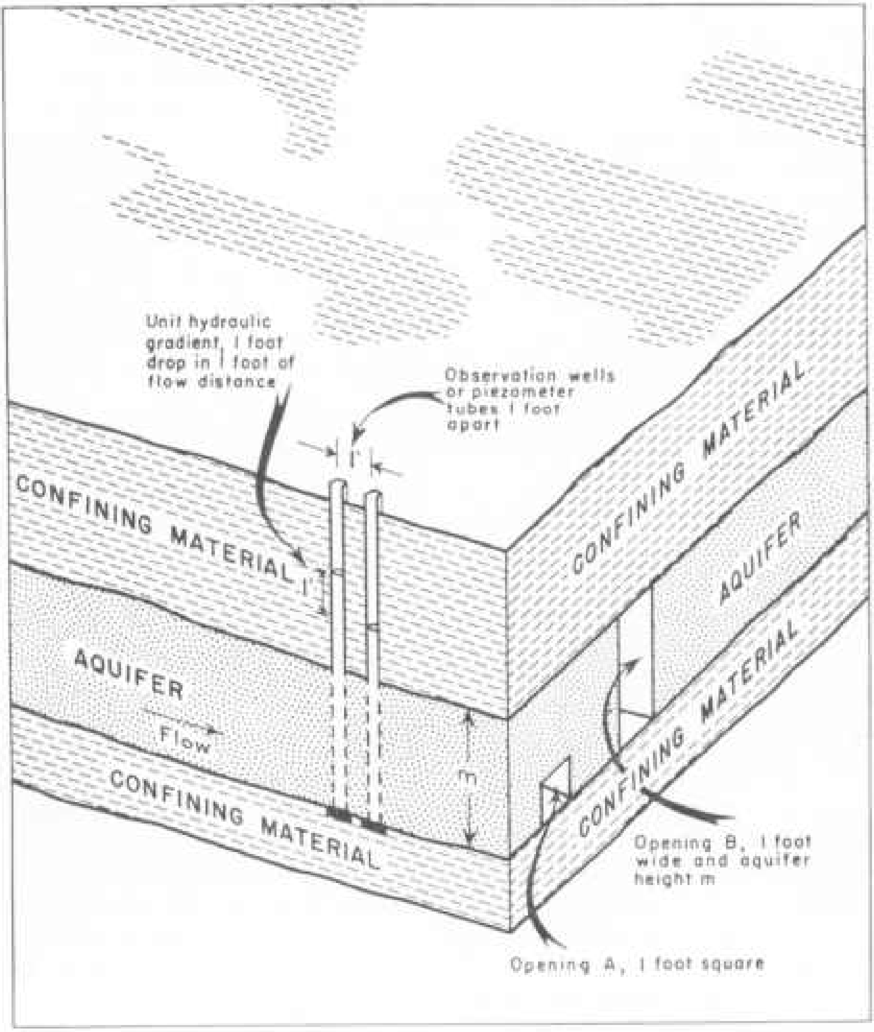

FIGURE 4. Diagram Explaining the Coefficients of Permeability and Transmissibility (from Ferris, 1955)

Layers of material of similar physical characteristics in an aquifer are assigned a coefficient of permeability, which multiplied by the thickness in feet of that material, provides a rough estimate of their coefficient of transmissibility. The sum of the coefficients of transmissibility of the various materials in the aquifer is considered to approximate the coefficient of transmissibility for the entire aquifer or geologic unit.

Aquifers, in addition to functioning as conduits through which water can move from areas of recharge to areas of discharge, function also as reservoirs which store large quantities of water. The coefficient of storage (S) is a term devised to characterize this hydraulic property of an aquifer. It is defined as the volume of water released or taken into storage per unit surface area of the aquifer per unit change in the component of hydraulic head normal to that surface. It is dimensionless. By using the coefficients of storage and transmissibility together, it is possible to predict the amount of drawdown that will occur at a given distance from a pumping well after pumping at a known rate for a given period of time. Such information is useful in planning the spacing of wells because it facilitates the prediction of the degree of hydraulic interference between wells and aids in computing the length of time a well can be pumped under various geohydrologic conditions.

Hydraulic Head and Movement

The rate of flow through permeable sand-sized earth materials is proportional to the hydraulic head. This fact was observed and demonstrated by Darcy in 1856 and is sometimes expressed by the formula $Q = PIA$ where:

Q = the quantity of water discharged per unit time
P = permeability of the material
I = the hydraulic gradient
A = the cross-sectional area through which the water must move

Hydraulic head, or pressure, may differ from one aquifer to another at the same place. It commonly varies from place to place even in the same aquifer. Water moves, in response to differences in hydraulic head, from points of high head to points of lower head. Hydraulic head in an aquifer is usually determined by measuring the water level in a well. Where these measurements are available from several wells ending in the same aquifer, a piezometric (or hydraulic head) map may be constructed. Such a map showing the direction of movement of ground water is useful in determining source and discharge areas of the water.

If the coefficient of transmissibility for a given aquifer is uniform, the quantity of water available from it should be progressively greater toward the southeast because the dipping of the aquifers in that direction causes them to be deeper and the water in them to be under greater hydraulic pressure. The greater depth to the aquifers permits greater drawdown in wells and, hence, somewhat greater well yields.

Salt-water Intrusion

Most of the water in the Chesapeake Bay and its tributaries is from one-third to one-half as salty as ocean water. It has a chloride content of 6,000 to 10,000 ppm (parts per million). The proximity of such a large body of saline or brackish water poses a hazard of serious concern in the eastern part of the County. Heavy pumping may draw this water into the aquifers and cause contamination of the fresh water. This hazard limits the amount of water that might otherwise be taken from some of the aquifers. No significant instances of salt-water intrusion have been reported within Anne Arundel County, but salt-water contamination of aquifers in the Baltimore industrial area has been extensive (Bennett, R. R. and Meyer, R. R., 1952, p. 124–171).

Factors that determine the extent or degree of contamination caused by salt-water intrusion due to overpumping are: 1) the relative hydraulic head between the aquifer and the salt-water body at the zone of infiltration into the aquifer; 2) the proportion of the total recharge area that is occupied by the salt-water body; 3) the thickness and permeability of confining beds overlying the aquifer (the silt or clay layer on the bottom of the Chesapeake Bay probably acts as a confining layer); and 4) the salinity of the intruding water.

Availability from Geologic Units

This investigation of the ground-water resources was devoted primarily to a study of the major water-bearing units in the County. These are the Patuxent, Patapsco, Raritan, Magothy, and Aquia Formations. In addition small ground-water supplies are obtained at a few places from the Monmouth and Calvert Formations and from the Pleistocene terrace deposits along the estuaries. Detailed information concerning the water-bearing properties of the minor aquifers is not available.

Each of these major aquifers has distinctive water-bearing characteristics which vary from one part of the County to another. In places some of the aquifers are separated from one another by aquicludes, or relatively impervious beds. In other places, sands in two or more formations are physically connected and behave hydraulically as one aquifer. Where the aquifers are hydraulically connected and there are differences in hydrostatic pressure between them, water may leak from one aquifer to another.

Patuxent Formation

The Patuxent Formation is the oldest of the unconsolidated sediments in the County. It consists of sand and gravel, sandy clay, and clay; the sand and gravel commonly occur in one or two widespread sheet-like units which constitute the water-bearing part of the formation.

The outcrop area of the Patuxent Formation forms a somewhat irregular band, approximately 4 to 5 miles wide, extending from Washington, D. C., to Baltimore (Pl. 3). A substantial part of the outcrop area lies northwest of Anne Arundel County, chiefly in Howard and Prince Georges Counties. The total area of outcrop along a 30-mile reach between Baltimore and Washington is about 120 square miles, of which only about 10 square miles is in Anne Arundel County. Thus precipitation in the adjoining counties is a source of recharge for much of the ground water in the formation in Anne Arundel

County. If precipitation on the outcrop area recharges the aquifer at roughly 0.5 mgd per square mile, then the total ground-water recharge along the 120-square mile belt of outcrop is on the order of 60 mgd.

The lithology of the Patuxent Formation in the outcrop area is variable. Details of the variability are described in a section summarizing ground-water conditions in the Maryland City area. Northwest of the −100-foot contour line on Plate 5, the thickness, extent, and position of the water-bearing sands is unpredictable. At some localities the sands are capable of yielding several hundred gallons of water per minute, but at other localities they are too thin or of too small lateral extent to yield more than a few gallons per minute to individual wells.

TABLE 4

Transmissibility, Permeability, and Storage Coefficients of the Patuxent Formation

Location	Coefficient of transmissibility (gpd/ft) T	Effective sand thickness (ft) M	Field coefficient of permeability (gpd/ft²) P_f	Coefficient of storage S	Length of drawdown phase of test (minutes)	Screen position referred to sea level (ft)
Glen Burnie Dorsey Road field	8,000	13	600	0.0001	480	−382 to −407
District Training School at Laurel	600	27	20+	—	179	−23 to −29 −36 to −55
Laurel Race Course	10,000	20	500	.00006	360	+94 to +84
Colony 7 Motel	15,000	46	300	.001	480	+19 to +9
Fort Meade	20,000	20	1000	—	1,440	−355 to −375
Kings Heights[2]	50,000	125	400	—	960	−674 to −694
Do[3]	15,000	40	380	—	1,110	−527 to −547
Sparrows Point district	40,000	50	800	.0006	120	−571 to −600
Do	80,000	80	1000	.0007	170	−587 to −649
Highlandtown district	6,000	50	120	—	69	−91 to −101 −115 to −125
Dundalk district	30,000	60	500	.0002	132	−224 to −239 −254 to −284
Beltsville-Muirkirk	600	12	50	.00001	139	—
Bladensburg	600	8[1]	70	—	271	—
Hyattsville	11,000	27	400	—	303	−102 to −132

[1] Total thickness of aquifer unknown, well penetrated only the thickness shown.

[2] Data for the lower sand.

[3] Data for the upper sand.

Southeast of the −100-foot line the sands in the Patuxent Formation appear to be more uniform in thickness and lateral extent. This was demonstrated during a pumping test near Glen Burnie when changes in the artesian head were transmitted through the sands to wells as much as 2 miles away. Southeastward from the Glen Burnie and Odenton areas few data are available concerning the thickness, extent, or hydraulic properties of the sands in the formation. Near Belair in Prince Georges County well logs show about 150 feet of water-bearing sand in the Patuxent Formation at a depth of 800 to 1,100 feet below sea level. Water levels in the formation in the Belair area are not available but they are probably a few tens of feet above sea level. There are no large users of ground water from the Patuxent in this area; hence, water levels in the formation should be essentially undisturbed in the area between Odenton and Belair. The analysis of the availability of ground water from the Patuxent Formation has been based on a determination of the hydrologic properties of its sands from several aquifer tests, chiefly on wells along the outcrop and near-outcrop areas of the formation. The data from these tests are summarized in Table 4.

Plate 11 serves to visualize the geology of the Patuxent Formation. The diagram illustrates the aquifer dipping beneath the land surface toward the southeast from its relatively narrow outcrop belt in the northwestern part of the County. The formation should be visualized as a conduit capable of transmitting water downdip from its area of outcrop. As the quantity of water percolating through a given cross section of an aquifer is proportional to the hydraulic gradient and the coefficient of transmissibility, it can be computed for any segment of an aquifer using the following modified form of the Darcy equation (Ferris, 1959, p. 148)

$$Q = TIL$$

where

Q = discharge or flow, in gallons per day

T = coefficient of transmissibility in gallons per day per foot

I = the hydraulic gradient, in feet per mile, assumed on the basis of water levels (hydraulic heads) lowered to the top of the formation

L = the length, in miles, of cross section through which the flow would occur.

Data obtained from aquifer tests in Anne Arundel County and adjacent areas show that the coefficients of transmissibility of the sands in the Patuxent Formation range from less than 1,000 to more than 75,000 gpd per foot (Table 4). These data were plotted on a map, and the County was divided arbitrarily into four segments or sections (A, B, C, and D) shown on Plate 11. The diagram, based on a total width of aquifer of 29 miles, shows that the most permeable segment, Section D, is in the vicinity of Baltimore County. Sections A, B, and C are the least permeable, having a coefficient of transmissibility of only 10,000 gpd per ft.

To use the formula $Q = TIL$ as a means of approximating the maximum possible theoretical flow through the aquifer, it is necessary to assume that it would be possible to cause water levels in the artesian part of the aquifer to be lowered to the top of the aquifer. Such lowering is assumed to take place across a strip along the south boundary of the County, parallel to the outcrop belt. Then the maximum theoretical rate of flow through each segment of the aquifer across the County would be:

Section A	$Q = 10{,}000 \times 60 \times 10$	=	6 mgd
B	$Q = 10{,}000 \times 62 \times 8$	=	5
C	$Q = 10{,}000 \times 57 \times 7$	=	4
D	$Q = 40{,}000 \times 62 \times 4$	=	10
Total	Q	=	25

The preceding analysis, which would allow a maximum theoretical flow of 25 mgd through the Patuxent Formation, assumes: 1) the sands in the aquifer are hydraulically interconnected; 2) their transmissibility is essentially constant along the designated aquifer strip; and 3) water levels in the deeper portions of the aquifer can be lowered to a level sufficient to cause hydraulic gradients approximating those assumed. It is doubtful if any of the above assumptions can be completely or even partially fulfilled. Therefore the quantity of 25 mgd of water capable of being transmitted through the Patuxent Formation is an approximate theoretical limit. The actual quantity available from the aquifer in the County may be somewhat more or less than 25 mgd, depending in part on the extent to which the aquifer is pumped in adjacent areas.

Another approach to the problem of approximating the quantity of water available from the Patuxent Formation consists of an analysis based on the computation of the drawdowns to be expected along an assumed line of favorably-positioned wells ending in the basal sand of the Patuxent Formation (Pl. 12). The analysis assumes that the perennial streams crossing the outcrop area serve as a recharge source and that pumping in the artesian area of the aquifer will result in no significant decline in water levels in its outcrop area. Computations based on the Theis nonequilibrium equation indicate that about 29 mgd can be obtained from 41 equally-spaced wells placed along a 30-mile line approximately 4 miles southeast of the outcrop belt of the formation. The analysis is predicated on the additional assumption that no large quantities of water are being withdrawn from the aquifer in adjacent areas. In order to simplify the computations involved in the analysis it was necessary to assume uniform coefficients of transmissibility and storage across the entire belt of aquifer involved. This assumption is reasonably valid, except in the vicinity of Baltimore City where the transmissibility of the aquifers ranges from 16,000 to 70,000 gpd per foot (Bennett and Meyer, 1952, table 9).

The approximate agreement of the estimates reached by the two methods of approach to the problem indicates that the values derived are in the right order of magnitude.

Patapsco Formation

The Patapsco Formation contains the most productive aquifers in Anne Arundel County. The importance of the formation is augmented because it occurs in the northern part of the County where the demand for water is the greatest. Although it was the source of water for several of the major well fields in 1960, it remains largely undeveloped as a ground-water source throughout most of the County.

Plate 6 shows the outcrop and recharge area of the Patapsco Formation and the altitude of the top of the formation where it dips beneath the overlying strata. The recharge area covers a belt approximately 6 miles wide across the northern part of the County which becomes progressively narrower southwestward. The maximum length of the Patapsco Formation across the recharge area supplying Anne Arundel County parallel to the strike is about 27 miles (Pl. 13). Its outcrop area is 140 square miles, of which 85 are in Anne Arundel and 55 are in Prince Georges County. On an assumed recharge rate of 0.5 mgd per square mile the total quantity of recharge on the outcrop area is on the order of 70 mgd.

Plate 10 shows that the hydraulic head (piezometric surface) in the Patapsco Formation is greatest in the western part of the area and is progressively lower toward the east. Water levels are as much as 140 feet above sea level in the western part and about at sea level in the vicinity of Marley Neck in the northeastern part of the County. The low hydraulic head in the northeastern part of the County is due chiefly to the effect of pumping from the Patapsco Formation in the Baltimore industrial area on the north side of the Patapsco River. Heavy pumping in the Glen Burnie and Odenton areas is reflected by localized cones of depression in those areas.

Table 5 shows the coefficients of transmissibility, permeability, and storage of the sands of the Patapsco Formation at places in and near Anne Arundel County. The coefficients of transmissibility range from 1,300 gpd per foot in the vicinity of Washington, D. C., to 52,000 gpd per foot at Annapolis. Coefficients of storage range from 0.00003 to 0.06. The average of nine values of the storage coefficient is 0.007.

An estimate of the maximum amount of water the sands in the Patapsco Formation may be capable of transmitting downdip from their outcrop area was made by treating the formation as a conduit and using the average hydrologic properties determined from aquifer tests. The concept of the formation

TABLE 5

Transmissibility, Permeability, and Storage Coefficients of the Patapsco Formation

Location	Coefficient of transmissibility (gpd/ft) T	Effective sand thickness (ft) M	Field coefficient of permeability (gpd/ft) P	Coefficient of storage S	Length of drawdown phase of test (minutes)	Screen position referred to sea level (ft)
Linthicum	5,000	25	200	—	175	−12 to −22
Glen Burnie						
Sawmill Creek	35,000	40	870	0.0005	495	−81 to −101
Odenton	37,000	50	740	.0002	452	+15 to −5
Glen Burnie						
Harundale	20,000	25	800	.00007	456	−70 to −95
Fort Smallwood	20,000	85	230	—	123	−339 to −358
Fort Meade	30,000	60	500	—	1,440	+10 to −10
Gambrills	40,000	—	—	—	185	—
Fort Meade	25,000	85	290	—	1,440	−60 to −80
Kings Heights	5,000	65	80	.00003	480	+31 to +16
	25,000	100	250	—	1,080	−100 to −120
	20,000	40	500	—	1,080	−260 to −280
Glen Burnie						
Dorsey Road	13,000	39	330	.0002	480	−76 to −81
Severna Park	18,000	65	280	—	240	−120 to −140
Pines-on-Severn	39,000	87	440	—	930	−381 to −401
Severndale	40,000	110	360	—	420	−377 to −387
						−416 to −426
Gibson Island	11,000	46	240	.06	240	−273 to −298
U. S. Naval Academy	52,000	140	370	.0001	1,440	−567 to −587
	16,000	24	670	—	1,440	−670 to −690
U. S. Naval Engr.						
Exper. Station	45,000	76	600	.0002	413	— to −498
Sparrows Point	29,000	90	320	.00005	96	—
Curtis Bay district	25,000	25	340	—	108	−96 to −106
Belair	16,000	100	160	.0004	13,680	−379 to −385
					($9\frac{1}{2}$ days)	−585 to −590
Fort Foote	1,300	9[1]	<140	—	357	−134 to −140

[1] Well did not reach bottom of aquifer but penetrated only the thickness shown.

functioning as a conduit is shown graphically in Plate 13. Using the modified form of the Darcy equation $Q = TIL$, about 25 mgd could theoretically be transmitted downdip from the recharge area. The computations are:

$$
\begin{array}{lll}
\text{Section A} & Q = 5{,}000 \times 45 \times 10 = & 2.2 \text{ mgd} \\
\text{Section B} & Q = 30{,}000 \times 45 \times 17 = & 23 \\
\hline
\text{Total} & Q & = 25.2
\end{array}
$$

It is unlikely that uniform gradients of a magnitude adequate to transmit this quantity of water could be developed along the southern boundary of the County. Thus, the quantity of 25 mgd is a theoretical upper limit of the rate of withdrawal of ground water from the formation across the entire area.

Raritan and Magothy Formations

Together, the sands in the Raritan and Magothy Formations form an aquifer which in 1960 was the source of water for the well fields supplying the City of Annapolis and the Crownsville State Hospital. A maximum of 3.5 mgd of water has been taken from it by the City of Annapolis alone. However, the water is high in iron content and low in pH (acidic) and is treated before use.

Plate 7 shows the altitude of the uppermost sand in the Magothy Formation and the outcrop area of the Raritan and Magothy Formations. The formations dip southeastward across the County at about 30 to 35 feet per mile. The length of the outcrop belt of the aquifer in the Raritan and Magothy Formations pertinent to Anne Arundel County is about 25 miles. This belt covers 78

TABLE 6

Transmissibility, Permeability, and Storage Coefficients of the Raritan and Magothy Formations

Location	Coefficient of transmissibility (gpd/ft) T	Effective sand thickness (ft) M	Field coefficient of permeability (gpd/ft.^{2}) P_f	Coefficient of storage S	Length of drawdown phase of test (minutes)	Screen position referred to sea level (ft)
Pines-on-Severn	17,000	30	570	—	135	−168 to −183
Crownsville	90,000	160	560	0.0003	1,735	−102 to −127
Sandy Point	22,000	24	900	.0002	2,880	−238 to −253
Governor Bridge	60,000	100	600	.001	480	−113 to −148
Davidsonville	45,000	50+[1]	<900	—	250	−194 to −204
Annapolis (City Water Works)	75,000	130	580	.0001	450	−163 to −213
Annapolis (Naval Academy)	23,000	110	210	—	267	−214 to −239 −260 to −296
Do	20,000	90	220	—	1,440	−295 to −315
Mt. Zion (Southern High School)	6,300	26	240	—	265	−386 to −406
Belair (Prince Georges County)	18,000	90	200	.0002	10,800 (7.5 days)	−22 to −28 −82 to −88 −202 to −208
Upper Marlboro (Prince Georges County)	17,000	10+[1]	<1,700	—	230	−195 to −203
Cheltenham (Prince Georges County)	17,000	23+[1]	<740	.00007	195	−180 to −201

[1] Well did not reach bottom of aquifer but penetrated only the thickness shown.

square miles, of which 70 square miles are in Anne Arundel County and 8 square miles are in Prince Georges County. Assuming an average rate of ground-water recharge of 0.5 mgd per square mile, the total quantity of water recharging the aquifer across the 25-mile long belt is on the order of 40 mgd.

Plate 15 shows the approximate hydraulic head in the upper sands of the Raritan and Magothy Formations. Comparison of this map with a topographic map shows that the head in the aquifer is generally highest in those areas which are topographically high and lowest in the topographically low coastal areas. This indicates that some water is moving vertically through the overlying Matawan and Monmouth Formations, which function hydrologically as confining layers. Apparently there has been no major decline in storage in the aquifer, because pumping by wells of the City of Annapolis of about 2.5 mgd (in 1960) has resulted in decline in the water level in the aquifer of only about 100 feet near the center of pumping and when the wells are shut down for short periods the water levels recover to within a few feet of their original static positions. Thus, there is no evidence of sustained overpumping in the area.

Coefficients of transmissibility, permeability, and storage for these sands have been determined by tests in and near Anne Arundel County. The results of the tests show that the coefficients of transmissibility range from 6,300 gpd per foot in the Mount Zion area to 90,000 gpd per foot in the Crownsville area (Table 6). Coefficients of storage, based on aquifer tests, range from 0.00007 to 0.001. Based on 6 values, the average storage coefficient is 0.0003.

On the concept of the aquifer functioning as a conduit transmitting water downdip from its recharge area, the theoretical maximum rate of flow across a section of aquifer normal to the outcrop area is about 27 mgd (Pl. 14):

$$Q = TIL$$

Section A:	$Q = 18{,}000 \times 28 \times 7 =$	3.5 mgd
Section B:	$Q = 75{,}000 \times 28 \times 9 =$	19 mgd
Section C:	$Q = 20{,}000 \times 28 \times 9 =$	5 mgd
Total Q	$=$	25.5 mgd

The practical limit of withdrawal from the sands in the Raritan and Magothy Formations may be somewhat more or less than the theoretical limit, because of the difficulty inherent in creating the maximum hydraulic gradients and because the conduit analysis assumes that all the water flows downdip from the outcrop area of the aquifer and does not take into account the water which moves laterally into the County from adjacent areas.

Aquia Greensand

The Aquia Greensand supplies most of the water in the part of the County south of Davidsonville and Annapolis. The greensand crops out extensively

TABLE 7

Transmissibility, Permeability, and Storage Coefficients of the Aquia Greensand

Location	Coefficient of trans-missibility (gpd/ft) T	Effective sand thickness (ft) M	Field coefficient of permeabil-ity (gpd/ft²) P_f	Coefficient of storage S	Length of drawdown phase of test (minutes)	Screen position referred to sea level (ft)
Cape St. Claire[1]	500	20	25	0.0004	120	−4 to −14
Galesville	13,000	100	130	—	358	−117 to −122
Deale	15,000	100	150	—	240	−175 to −180
Randle Cliffs (Calvert County)	10,000	—	—	—	130	−358 to −372

[1] The water-bearing sand at this site is believed to be isolated from the main body of the formation.

in the central part of the County (Pls. 8 and 16). Its outcrop belt extends beneath the Chesapeake Bay to the northeast and into Prince Georges County on the southwest. Most of the artesian water in the greensand in Anne Arundel County enters the aquifer along a 20-mile belt extending southwestward from the mouth of the Magothy River. The total area of outcrop of the greensand across this belt is about 110 square miles, of which 65 square miles are in Anne Arundel County and 45 square miles are in Prince Georges County. On an assumed rate of recharge of 0.5 mgd per square mile, the quantity of recharge in the outcrop belt is about 55 mgd.

The Aquia Greensand dips southeastward at slopes ranging from less than 15 to nearly 30 feet per mile (Pl. 8). Near Holland Point the top of the formation is about 200 feet below sea level. Water levels in it range from a few to 50 feet above sea level (Pl. 16). In general, the central upland parts of the County, where water levels are highest (above an altitude of 20 feet), are recharge areas for the formation. Flowing wells have been drilled at a few low-lying sites in the southern part of the County, especially near Deale and in the vicinity of Herring Bay.

Individual wells tapping the greensand produce as much as 210 gpm, but probably larger yields can be obtained from properly constructed wells of a diameter greater than existing wells.

Table 7 summarizes the hydrologic coefficients determined for the greensand. Coefficients of transmissibility, obtained from three aquifer tests range from 500 to 13,000 gpd per foot. A coefficient of storage of 0.0004, based on a brief test at Cape St. Claire, is in the artesian range. As many of the wells in the greensand are screened in only a part of the water-yielding segment of the aquifer, the coefficients of transmissibility are probably in the low range. Therefore, an average transmissibility of 13,000 gpd per foot was used in computing the theoretical rate of flow of 5 mgd through the aquifer. The estimate of 5 mgd is based on the aquifer behaving as a conduit transmitting water from the outcrop area to a hypothetical discharge area across the southern part of the County (Pl. 17). Since the computed theoretical rate of flow through the aquifer depends on the doubtful assumption that sufficiently steep hydraulic gradients can be created in the artesian areas of the County, the quantity of 5 mgd is a theoretical limit, probably incapable of attainment.

Pleistocene Deposits

Deposits of Pleistocene age occur throughout a large section of the County; they have been classified (Otton, 1955, p. 99–106) into upland and lowland deposits.

The upland deposits consist of sand, gravel, and clayey silt capping the hill-crests along the interstream divides, chiefly south of latitude 39°05′ along the upper Severn River. As only a small part of the upland deposits are saturated and as they are commonly tapped only by dug wells, they are unimportant as a source of ground water in the County.

The lowland deposits are largely marine or estuarine terrace materials which underlie extensive areas along the Bay front of the County (Clark, 1916). The deposits consist of sand, gravel, clay, and silt and in places their thickness is 50 feet or more. Locally, dug wells are common in the deposits where they are sandy and the water table is sufficiently close to the surface for them to be adequately saturated. Along the valley of the Patapsco River and at other similar places the lowland deposits may yield large quantities of water. Bennett and Meyer (1952, p. 72) report that a collector-type well tapping the lowland deposits near Relay in adjacent Baltimore County yields about 1,000 gpm. Possibly similar yields could be obtained from large-diameter wells having high specific capacities at places in Anne Arundel County along the larger stream valleys, particularly along the Patuxent and Patapsco Rivers.

Availability in Selected Areas

Ground-water conditions differ from one part of the County to another because the geology and hydrology differ from one area to another. The Anne Arundel County Planning and Zoning Commission designated ten areas (Pl. 18) in which it is assumed that population growth and industrial development will be the greatest. The accuracy of the estimates of the quantity of ground water available from each of the areas depends on the amount and type of data available. In the three areas (Glen Burnie, Maryland City, and Odenton-Millersville) where the total thickness and character of the unconsolidated deposits are known, estimates have been made of the total amount of ground water available. In the other seven areas, only the upper part layer of the unconsolidated sediments has been penetrated by drilling and in these areas estimates are given only for the availability of water from aquifers that have been drilled. Future drilling and testing of the strata will undoubtedly show that the quantity of water available in some areas is larger than the estimated quantities because additional water-bearing strata will be found at greater depths.

Hydraulic interference must be expected where wells in adjacent areas tap the same aquifer to the extent that the cones of depression or interference spread beyond the area.

The estimates for the quantities of water available from a specific area are based on water levels in 1960. The quantities will be less if and when water levels in the aquifers are lowered below the 1960 level. Because of uncertainties as to which areas will be developed first, no attempt is made to predict the amount of water that will be available in each area at the time it is developed.

Seven of the ten special areas are sufficiently near salt-water bodies to warrant concern about the intrusion of salt water from the Chesapeake Bay and its estuaries. The availability of ground water in some of these areas may be limited more by the hazard of aquifer contamination than it is by the ability of the formations to transmit water. Generally, existing data are inadequate to properly evaluate the hazard of salt-water contamination in the areas. Because the detailed studies needed to properly evaluate the problems of salt-water intrusion are beyond the scope of this investigation, the estimates of the quantity of water available from specific areas are based mainly on the ability of the aquifers to transmit water. The estimates have not been modified to reflect the possible hazard of salt-water intrusion resulting from the withdrawal of the ground water.

Annapolis

The Annapolis area covers about 24.5 square miles in the central eastern part of the county (Pl. 18). In 1960 about 4.2 mgd of ground water was pumped from aquifers in the area (Table 2). On the basis of the projected population increase, it is predicted that there will be a demand for over 6 mgd by 1980 (Lyon, 1961). It is concluded from this study of the ground-water resources that several times more than the required 6 mgd can be obtained if the aquifers underlying the area are properly developed. Proper development of the ground-water reservoirs implies adequate well spacing, proper screen emplacement, and effective well development. Also, well casings should be properly sealed so as to minimize vertical leakage between aquifers.

The yields of the most productive wells in the area range from 235 to about 1,550 gpm; specific capacities are as high as 32 gallons per foot (Table 8). The bottom of the deepest well screen is about 690 feet below sea level, where fresh water is obtained from a sand in the Patapsco Formation.

Table 9 presents graphically a lithologic column based on data from a test well at the U. S. Naval Academy and from a deep well at the Annapolis City

TABLE 8

Data on High-Capacity Wells in or near the Annapolis Area

Owner	Owner's number	Year drilled	Altitude of land surface (ft)	Depth of well (ft)	Altitude of screen (ft)	Altitude of water level (ft)			Yield (gpm)	Specific capacity (gpm/ft of drawdown)	Aquifer
						Static	Pumping	Date			
U. S. Naval Academy	9	1933	9	306	−214 to −240 −263 to −297	16.8 13.0 8.2	— — —	3-20-34 6-7-51 6-6-61	235	—	Raritan and Magothy Formations
Do	11	1939	10	583	−496 to −563	8[1]	−97[1]	1-3-39	1510[1]	14	Patapsco Formation
Do	12	1944	14	606	−504 to −574	—	—	11-10-45	1280[1]	15	Do
Do	13	1960	5	698	−563 to −593 −666 to −691	−1.7	−146	12-20-60	1548	11	Do
City of Annapolis	2	1939	15	250±	—	1.4[2]	−44	5-20-61	750	<16	Raritan and Magothy Formations
Do	5	1947	24	248	—	−.8[2]	−47	5-20-61	1050	<23	Do
Do	6	1947	27	242	−165 to −215	−1.7[2]	−45	5-23-61	1050	<22	Do
Do	7	1955	120	345	−167 to −225	−8[2]	−47	5-23-61	1250	<32	Do

[1] Reported by driller.
[2] After only 2 to 12 hours of recovery.

water works. Although an estimated 1,300 to 1,500 feet of sedimentary strata underlie the area, reliable geohydrologic data are unavailable below a depth of 750 feet. Within the 750 feet of strata at least four important aquifers are present. Two of them are sands in the Patapsco Formation, another is a sand in the Raritan and Magothy Formations, and the fourth, and uppermost, is the Aquia Greensand.

The Patapsco Formation contains the most productive aquifers. In 1960, an average of 1.5 mgd of water was pumped from them by wells at the U. S. Naval establishments. The uppermost sand in the Patapsco is about 40 feet thick; it has not been tested and its hydrologic properties are unknown. The middle sand, occurring at a depth of 460 to 600 feet is the major aquifer in the area. Several large-capacity wells at the Naval Academy are screened in it. At a depth of approximately 670 feet is another sand which is about 30 feet thick. It has not been previously used as a source of water, but was tested in 1960 and found to be water-bearing. After 1961 it will supply a part of the water pumped from a large-capacity, multiple-screened well at the Academy.

Figure 5 shows the distance-drawdown relationship for the water-bearing sand in the Patapsco Formation from 450 to 600 feet below the land surface. The graph, based on an analysis using the Theis nonequilibrium formula, may be used to predict hydraulic interference between wells tapping the same aquifer. The graph is based on an average rate of withdrawal of 1 mgd. Declines in

TABLE 9

Geologic, Hydrologic, and Chemical Data Used in Estimating the Availability and Quality of Ground Water in the Annapolis Area

GEOHYDROLOGY				DATA USED IN COMPUTATION					QUALITY OF WATER	
Geologic unit	Position relative to sea level (ft)	Composite geologic section[1]	Aquifer or aquiclude	Available drawdown (ft)	Transmissibility (gpd/ft) T	Maximum hydraulic gradient (ft/mi) I	Width of section (mi) L	Quantity of water available (mgd) Q = TIL	Number of analyses	Range in chemical constituents and properties of ground water (in ppm, except for pH)
Aquia Greensand	Sea level		Aquifer	50	5,000[2]	20	4	5.6	8 8 8 8	Iron (Fe) 0.1 – 4.0 Chloride (Cl) 2.0 – 882 Hardness as $CaCO_3$ 9 – 610 pH 5.1 – 7.4
Monmouth and Matawan Formations	−100		Aquiclude							
Magothy and Raritan Formations	−200		Aquifer		untested	25			1 1 1 1	Iron (Fe) 11 Chloride (Cl) 2.0 Hardness as $CaCO_3$ 36 pH 5.6
			Aquiclude							
	−300		Aquifer	120[3]	75,000[2]	25	4	7.5	10 9 6 9	Iron (Fe) 4.5 – 18 Chloride (Cl) 1.0 – 3.0 Hardness as $CaCO_3$ 34 – 82 pH 5.9 – 6.3
Patapsco Formation			Aquiclude							
	−400		Aquifer		untested				1 1 1 1	Iron (Fe) 20 Chloride (Cl) .8 Hardness as $CaCO_3$ 29 pH 6.1
			Aquiclude							
	−500		Aquifer	450	52,000	40	4	8.1	2 1 1 2	Iron (Fe) 1.5 – 26 Chloride (Cl) .9 Hardness as $CaCO_3$ 37 pH 5.2 – 6.1
	−600		Aquiclude							
	−700		Aquifer	675	7,000	40	4	1.1	1 1 1 1	Iron (Fe) 16 Chloride (Cl) .7 Hardness as $CaCO_3$ 26 pH 5.7
			Untested – data unreliable or lacking below approximately 700 feet.							

[1] Based chiefly on log of test well drilled at the U. S. Naval Academy in 1960.

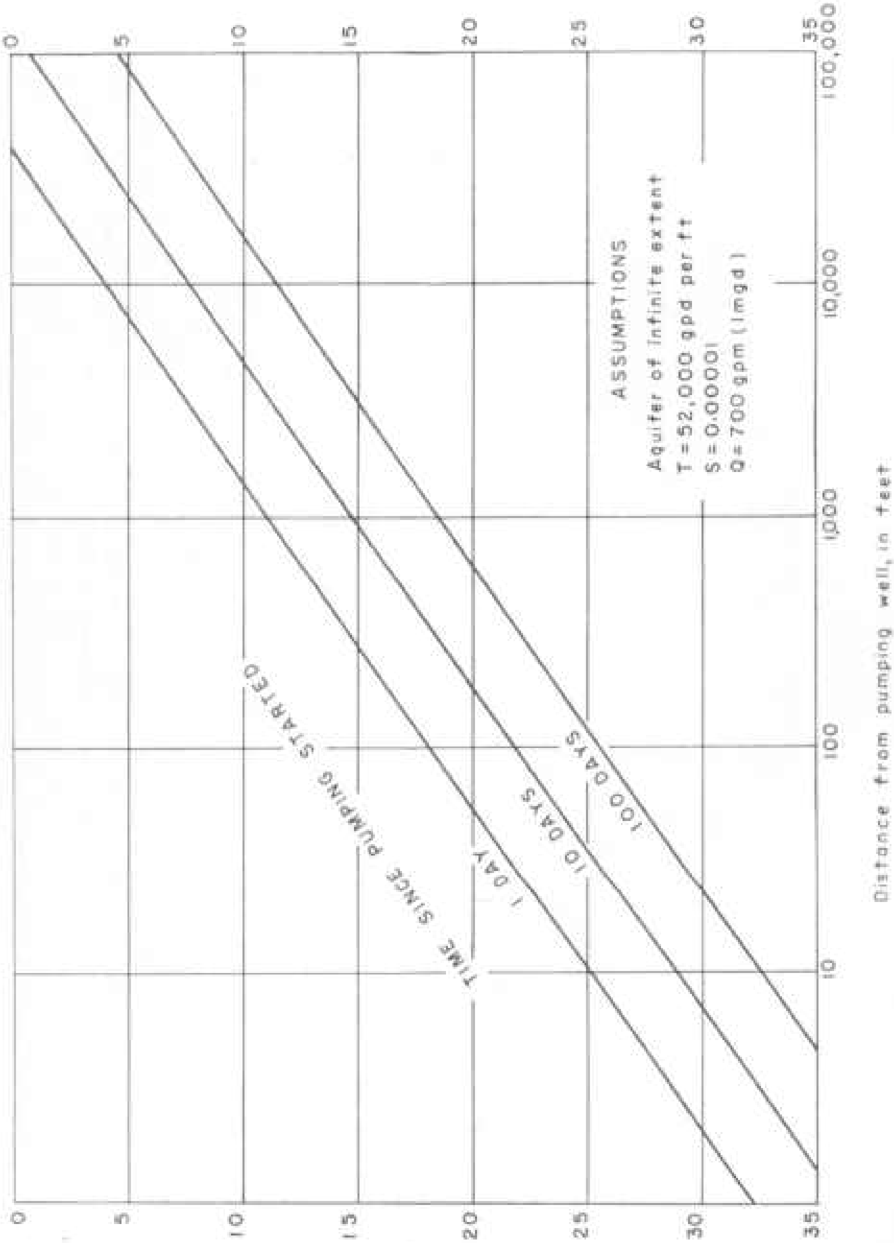

FIGURE 5. Graph Showing Theoretical Declines in Hydraulic Head (Drawdowns) Caused by Pumping from a Sand in the Patapsco Formation in the Annapolis Area

water level based on higher or lower rates of discharge may be computed directly from the graph as the drawdowns are directly proportional to the pumpage.

At Annapolis at a depth of about 200 feet, a clay layer, 30 feet thick, separates a sand of similar thickness in the Magothy Formation from a water-yielding sand more than 100 feet thick in the Raritan Formation. At the City of Annapolis well field, geologic logs indicate the two sands are one hydraulic unit. Hence, in this report the two sands are designated as the aquifer in the Magothy and Raritan Formations.

At the Annapolis water plant the potential drawdown of wells screened in the aquifer in the Raritan and Magothy Formations is smaller than it is in the underlying Patapsco Formation. Based on a coefficient of transmissibility of 75,000 gpd per ft, and a hydraulic gradient of 25 feet per mile, it is estimated that across a 4-mile strip of the aquifer, about 7.5 mgd could be withdrawn without exceeding the available drawdown of 120 feet.

The pumpage in 1960 (2.4 mgd) from the aquifer in the Raritan and Magothy Formations at the Annapolis City water works constituted only about 33 percent of the total quantity of water theoretically available from the aquifer in the area. Figure 6 shows the theoretical drawdown to be expected in wells ending in the aquifer of the Raritan and Magothy Formations at various distances from a well pumping 1 mgd (approximately 700 gpm) along a line parallel to the strike of the outcrop area. The graph shows the drawdowns at the end of 10 days and after virtual stabilization at 100 days. It is based on the Theis nonequilibrium formula.

At the Naval Academy, where a 30-foot clay layer separates the sands of the Raritan from the sands of the Magothy, tests show the transmissibility to be about 23,000 gpd per foot, or only about one-third as great as at the well field of the City of Annapolis.

In the vicinity of the Naval Academy, the aquifer in the Raritan and Magothy Formations (altitude -230 to -360 feet) is tapped by only a few wells and little water is pumped from it chiefly because its iron content is higher than that of the other water-bearing sands. Therefore, the hydraulic heads (water levels) in the aquifer are high, above sea level in most places, and thus the aquifer is protected from infiltration of brackish water from the nearby Severn River. Therefore, the aquifer in the Raritan and Magothy Formations may be functioning as a barrier preventing brackish water from contaminating the sands in the underlying Patapsco Formation. It is suggested that no large additional supplies be developed in the Raritan and Magothy Formations in this part of the Annapolis area until the hazard of salt-water intrusion has been studied more thoroughly.

In 1960, the Aquia Greensand furnished much of the water pumped from domestic and small commercial wells in the Annapolis area. Properly constructed 6-inch diameter wells south and east of Annapolis probably will yield

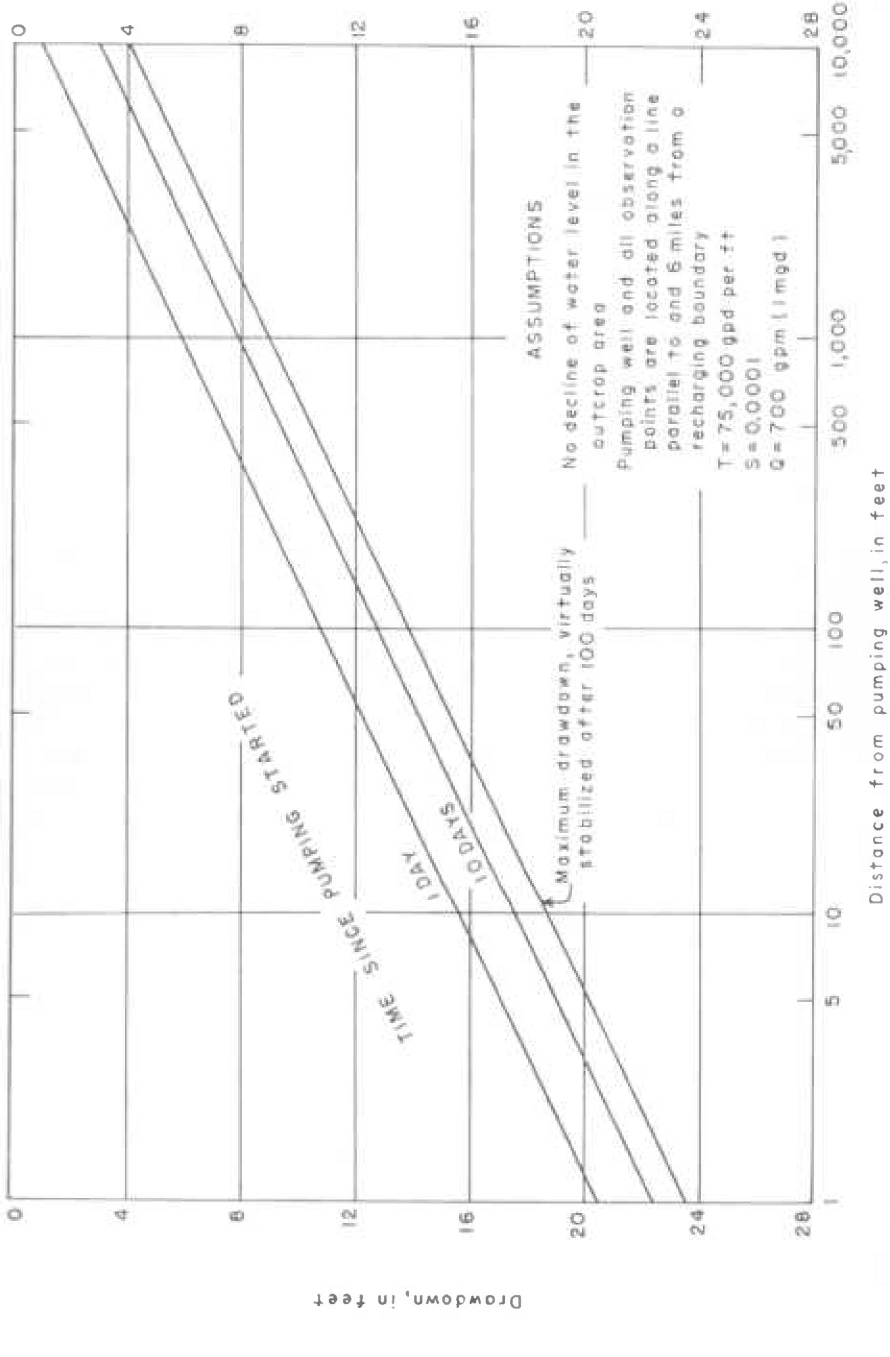

FIGURE 6. Graph Showing Theoretical Declines in Hydraulic Head (Drawdowns) Caused by Pumping from the Aquifer in the Raritan and Magothy Formations at the Annapolis Water Plant.

50 to 150 gpm from the Aquia Greensand, but to the northwest wells will yield less water, as the aquifer thins and disappears in that direction. Because of its moderately low transmissibility, the limited available drawdown, and the imminent danger of salt-water contamination along the estuaries, the Aquia Greensand is not considered a source of large ground-water supplies near Annapolis.

To evaluate the potential ground-water supply for the area, it was assumed that water levels in all artesian aquifers could be lowered to the top of the aquifer and that the aquifers would function as conduits transmitting water across an arbitrary 4-mile strip. Using the formula $Q = TIL$, the maximum theoretical flow across each strip of aquifer is approximately (from Table 9):

Aquifer	Total flow at assumed maximum hydraulic gradient (mgd)
Aquia Greensand	0.4
Raritan and Magothy Formations	7.5
Patapsco Formation	
(sand at −460 to −600 feet)	8.3
(sand at −670 to −700 feet)	1.1
Total	17.3

The theoretical limit of ground water which could be transmitted across a 4-mile wide strip parallel to the strike of the formations is thus about 17 mgd. Actually somewhat less than this quantity could be obtained, chiefly because of the difficulty involved in creating the necessary hydraulic gradients.

Glen Burnie

The Glen Burnie area includes about 14 square miles of urbanized land in the central northern part of the County (Pl. 18). Existing water supplies are derived chiefly from three well fields owned and operated by the Anne Arundel County Sanitary Commission. These are known locally as the Dorsey Road, Sawmill Branch, and Harundale well fields. During 1960, daily average water use was about 3.7 mgd; peak demand is estimated to be about 7.0 mgd. About 90 percent (3.4 mgd) of the ground water used in the area is pumped from the wells of the Sanitary Commission. It is estimated that the water demand in the area by 1980 will be 15 mgd (Lyon, 1961) and the peak demand may be on the order of 30 mgd.

The Glen Burnie area is underlain by about 400 to 500 feet of sedimentary strata which contain the only two aquifers, sands in the Patuxent and Patapsco Formations. These formations are separated by about 200 feet of clay, known as the Arundel Clay which effectively seals the water-bearing sands in the Patuxent from those in the Patapsco.

TABLE 10

Data on High-Capacity Wells in or Near the Glen Burnie Area

Owner	Name of well field	Owner's number	Year drilled	Altitude of land surface (ft)	Depth of well (ft)	Altitude of screen (ft)	Altitude of water level (ft)			Yield[1] (gpm)	Specific (capacity gpm/ft of drawdown)	Aquifer
							Static	Pumping[1]	Date			
Anne Arundel County Sanitary Commission	Sawmill Creek	1	1926	30	65	—	27	—	1961	220	—	Patapsco Formation
Do	do	2	1941	57	95	−8 to −38	35	3	7/24/41	280	9	Do
Do	do	3	1945	42	78	−21 to −31	—	—	1945	150	—	Do
Do	do	4	1947	57	102	−23 to −45	29	−5	4/9/47	290	9	Do
Do	do	5	1947	39	153	−87 to −107	29	−29	6/4/47	250	4	Do
Do	do	6	1953	43	151	−88 to −108	31	−77	11/18/53	490	5	Do
Do	do	7	1953	56	160	−84 to −104	40	−72	12/11/53	400	4	Do
Do	Dorsey Road	1	1955	70	131	−40 to −51	59	18	12/6/55	450	11	Do
Do	do	2	1956	68	510	−417 to −442	56	−59	1/13/56	475	4	Patuxent Formation
Do	do	3	1956	62	153	−71 to −91	55	10	12/6/55	450	11	Patapsco Formation
Do	do	4	1957	87	186	−84 to −99	54	−70	10/19/57	375	3	Do
Do	do	5	1957	66	474	−383 to −408	32	−103	11/15/57	450	3	Patuxent Formation
Do	do	11	1957	73	181	−88 to −108	60	−97	9/12/57	375	2	Patapsco Formation
Do	do	13	1957	85	517	−412 to −432	54	−129	10/31/57	375	2	Patuxent Formation
Do	do	14	1961	85	157	−47 to −72	67	−44	4/21/61	200	1.5	Patapsco Formation
Do	Harundale	1	1948	31	123	−67 to −92	27	−45	7/3/51	440	6	Do
Do	do	2	1949	38	115	−52 to −77	31	−27	1/ /49	450	8	Do
Do	do	3	1955	28	180	−132 to −152	28	−82	9/9/55	500	5	Do
Do	do	4	1955	42	206	−144 to −164	29	−3	8/2/55	500	16	Do
Two Guys Shopping Center	—	1	1957	55	119	−44 to −64	23	−7	7/22/57	270	9	Do
Do[2]	—	2	1957	59	121	−40 to −62	27	−14	7/29/57	270	7	Do
Do	—	3	1957	61	120	−47 to −59	29	−11	8/5/57	150	4	Do
Do[2]	—	4	1957	60	122	−50 to −62	28	−40	8/19/57	165	2	Do
Holy Trinity Elementary School	—	—	1957	63	168	−93 to −105	25	−20	9/7/57	200	4	Do
Ritchie Farmers Market	—	—	1960	85	146	−51 to −61	54	−52	10/5/60	290	3	Do
Arundel Arena	—	—	1960	20	230	−186 to −196 −200 to −210	−6	−159	6/13/60	250	2	Patuxent Formation

[1] Reported by driller. [2] Recharge well.

TABLE 11

Geologic, Hydrologic, and Chemical Data Used in Estimating the Availability and Quality of Ground Water in the Glen Burnie Area

GEOHYDROLOGY				DATA USED IN COMPUTATIONS					QUALITY OF WATER	
Geologic unit	Position relative to sea level (ft)	Composite geologic section[1]	Aquifer or aquiclude	Available drawdown (ft)	Transmissibility (gpd/ft) T	Maximum hydraulic gradient (ft/mi) I	Width of section (mi) L	Quantity of water available (mgd) Q = TIL	Number of analyses	Range in chemical constituents and properties of ground water (in ppm, except for pH)
Patapsco Formation	Sea level −100		Aquifer	100±	30,000[2]	50	4	6.0	22 21 12 23	Iron (Fe) 0.00 – 0.92 Chloride (Cl) 1.0 – 4.9 Hardness as $CaCO_3$ 4.0 – 38 pH 4.5 – 6.5
Arundel Clay	−200 −300		Aquiclude							
Patuxent Formation	−400		Aquiclude							
			Aquifer	400	10,000	100	4	4.0	5 4 2 5	Iron (Fe) 0.38 – 3.0 Chloride (Cl) .2 – 2.0 Hardness as $CaCO_3$ 2 – 4.3 pH 4.5 – 5.4
Crystalline Rocks			Aquiclude							

[1] Based chiefly on log of test well drilled at the Dorsey Road well field.

The yields of high-capacity wells range from 150 to 500 gpm; specific capacities are as high as 16 gallons per foot of drawdown. The two best wells are screened in the Patapsco Formation at depths of from 150 to 200 feet (Table 10). Most of the large-capacity wells are gravel walled and 8 or more inches in diameter.

During 1960 about 80 percent of the ground water used in the area was from the Patapsco Formation and about 20 percent from the Patuxent Formation. Drawdowns in three wells tapping the Patuxent Formation were on the order of 125 feet below an initial static level of 50 feet above mean sea level. An additional 325 feet of drawdown was available in the formation in the vicinity of the well field. The limit of available drawdown is assumed to be the top of the water-bearing sand at an altitude of −400 feet. The Patuxent Formation has been only partially utilized as an aquifer to date (1960).

Table 11 provides data used to compute the theoretical maximum flow across a 4-mile wide strip of the aquifers, based on the creation of relatively steep hydraulic gradients between the top of the aquifers and the essentially saturated outcrop area a few miles distant (updip). For the sand at the base of the Patuxent Formation the maximum possible hydraulic gradient is about 100 feet per mile. On the basis of a transmissibility of 10,000 gpd per foot, and using the formula $Q = TIL$:

$$Q = 10{,}000 \times 100 \times 4 = 4{,}000{,}000 \text{ gpd (4.0 mgd)}$$

Approximate agreement with the quantity of 4.0 mgd of water may be derived from the right-hand side of Plate 12 (B) and the discussion on page 22. The figure shows that a line of 6 wells in the Patuxent Formation in the Glen Burnie area, spaced 4,000 feet apart, would reach across 3.7 miles. These wells, pumping at a rate of 500 gpm each, would yield 3,000 gpm or about 4.3 mgd. Drawdowns in the wells should remain several feet above the top of the aquifer, unless the well spacing was substantially decreased or the hydraulic interference resulting from pumping in adjacent areas were to be greater than assumed in the analysis in Plate 12.

The accuracy of the hydrologic coefficients used in the preceding discussion is confirmed by the record of water levels in a 530-foot deep observation well at Glen Burnie (fig. 7) screened in the Patuxent Formation. The water level in this well fluctuated only slightly during the period from mid-1948 until mid-1957. In August 1957 pumping began from the initial supply well in the Patuxent in the Dorsey Road well field. The effect of pumpage on the water level in the observation well was immediate and marked—the water level began to decline. A second well to the Patuxent was completed shortly thereafter, and since 1957 the water level in the observation well has fluctuated chiefly in response to the pumping regimen at the Dorsey Road well field. During the interval from August 1957 to August 1960 the water level in the observation

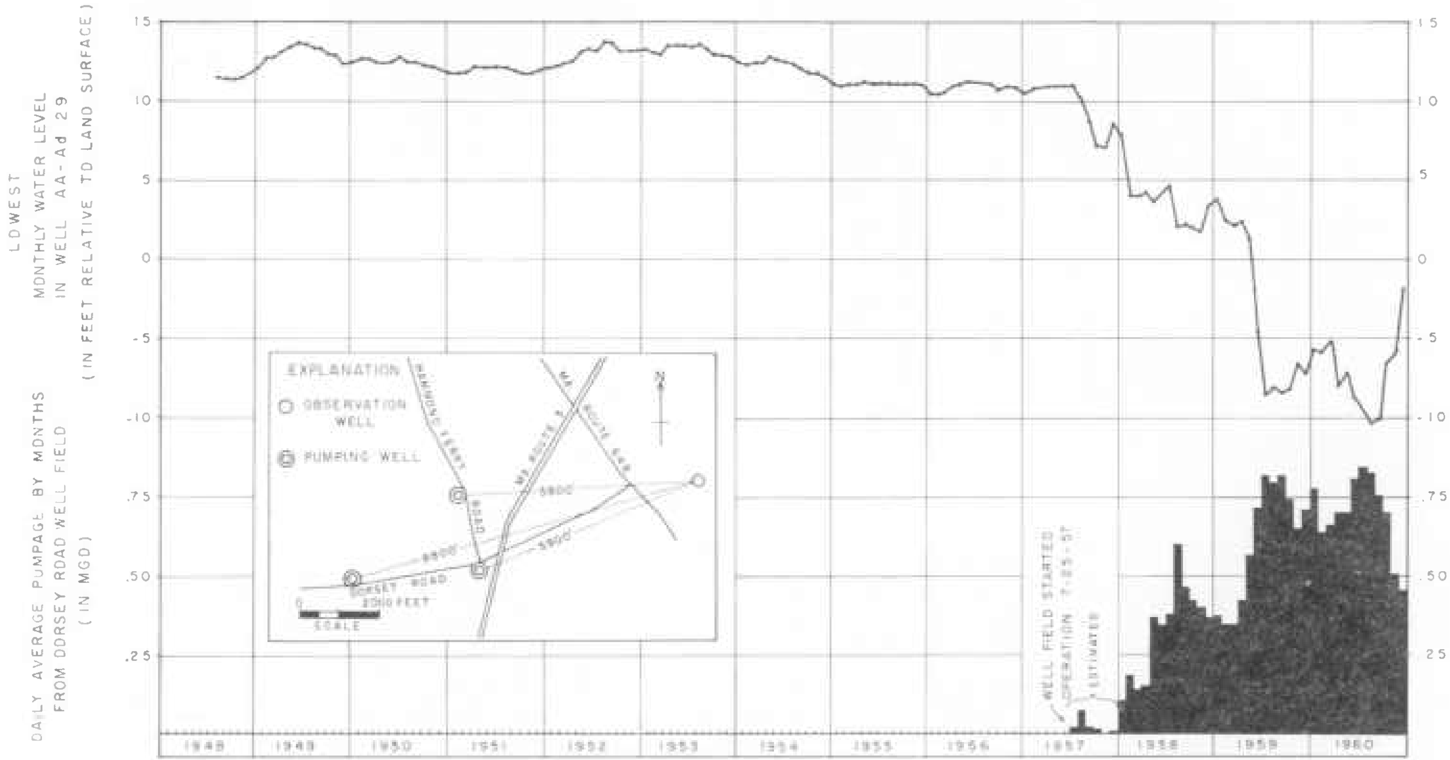

FIGURE 7. Record of Water Level in a 530-foot Unused Well at Glen Burnie Showing Effect on Water Levels Caused by Pumping from a Sand in the Patuxent Formation

well declined about 22 feet. Pumping rates during this period were as great as 0.8 mgd. Theoretical declines in water level computed for the observation well, based on the actual rates of pumping, agree within about 10 percent of the actual declines.

To estimate the availability of water from the sand in the overlying Patapsco Formation, the conduit analysis was used, assuming a hydraulic gradient of 50 ft per mile and a transmissibility of 30,000 gpd per ft. The computation of the rate of flow through the sand ($Q = TIL$) is:

$$Q = 30{,}000 \times 50 \times 4 = 6{,}000{,}000 \text{ gpd } (6.0 \text{ mgd})$$

Thus the theoretical limit of the rate of flow through both artesian aquifers is on the order of 10 mgd across the 4-mile wide strip parallel to the strike of the recharge belt.

The Glen Burnie area is in the outcrop and recharge belt of the Patapsco Formation, although the water in the sands at altitudes of −25 to −100 feet below sea level occurs under semiartesian conditions. The source of this water is undoubtedly local recharge in or near the Glen Burnie area. If it is assumed that ground-water recharge to the Patapsco Formation in the 14 square miles designated as the Glen Burnie area were on the order of 0.5 mgd per square mile (p. 13), then about 7 mgd would be available on a sustained basis.

It appears that the prospects for future development of ground-water supplies in the Glen Burnie area are about equal for the Patuxent and Patapsco

TABLE 12

Data on High-Capacity Wells in or near the Governor Bridge Area

Owner	Owner's number	Year drilled	Altitude of land surface (ft)	Depth of well (ft)	Altitude of screen (ft)	Altitude of water level (ft) Static	Pumping	Date	Yield (gpm)	Specific capacity (gpm/ft of drawdown)	Aquifer
U. S. Air Force	2	1960	123	272	−114 to −147	34	−18	8/15/60	340	6	Raritan and Magothy
A. A. County Board of Education—(Davidsonville Elem School)	3	1960	143	344	−196 to −201	28	—	11/23/60	150	—	Do
Belair	PW 1	1959	113	192	+3 to −79	48	10	9/28/59	500	13	Do
Belair	PW 2	1959	113	700	−344 to −359 −385 to −400 −542 to −587	48	−60	8/25/59	1230	11	Patapsco

Formations. Although the Patuxent Formation has the lower potential, 4 mgd, only about one-quarter of this quantity (0.9 mgd) was used in 1960; the Patapsco Formation has the higher potential (6.0 mgd), but more than one-half (3.2 mgd) of its potential was being used in 1960.

The total ground-water potential for the Glen Burnie area is only two-thirds of the estimated average water demand of 15 mgd for the area by 1980. The 5 mgd difference can be made up by tapping the aquifers beyond the arbitrary limits of the area.

Governor Bridge

Ground water is abundant in the Governor Bridge area (Pl. 18), but only relatively small quantities of it are being used. Predictions of future needs for the area, based on trends in 1960, indicate that 120,000 gpd will be required by 1980 (Lyon, 1961).

The largest well in the area is at the U. S. Air Force installation north of Davidsonville. The well has yielded about 335 gpm during testing from the aquifer in the Magothy and Raritan Formations. However, the installation uses only about 10,000 gpd or a small fraction of the capacity of the well. The only other ground-water users in the area are the many scattered rural homes or farms. Heavy pumping at the well field at Belair, 4 miles to the northwest in Prince Georges County, will reduce the amount of water available in the Governor Bridge area. Table 12 presents details on four of the wells of largest capacity in or near Governor Bridge.

Table 13 summarizes the available geologic and hydrologic information. Data for the upper 300 feet of strata were obtained from wells at the Air Force installation. Data for the lower 800 feet of strata are from wells at Belair. They are included in the table because the geologic conditions in the Governor Bridge area are believed to be similar to those at Belair. However, extrapolation of data into nearby areas is somewhat hazardous as the water-bearing characteristics and dimensions of aquifers can change within a few miles.

Sands in the Raritan and Magothy Formations are present at altitudes of about -30 to -150 feet in this area. They are separated from sands in the underlying Patapsco Formation by a 50-foot clay layer. An aquifer test at the Air Force transmitter station yielded coefficients of transmissibility and storage of 60,000 gpd per foot and 0.001 respectively. Aquifer tests at Belair indicate that the transmissibility of the aquifer decreases to about 18,000 gpd per foot at that locality.

The theoretical drawdowns in the aquifer in the Magothy and Raritan Formations, on the basis of computations using the Theis nonequilibrium equation, are shown in figure 8. The figure shows that the drawdown at a distance of 1 mile from a well pumping 700 gpm will be about 4.5 feet after 100 days of pumping. During this time the well would have furnished about 100 million gallons of water.

TABLE 13

Geologic, Hydrologic, and Chemical Data Used in Estimating the Availability and Quality of Ground Water in the Governor Bridge Area

GEOHYDROLOGY				DATA USED IN COMPUTATIONS					QUALITY OF WATER	
Geologic unit	Position relative to sea level (ft)	Composite geologic section[1]	Aquifer or aquiclude	Available drawdown (ft)	Transmissibility (gpd/ft) T	Maximum hydraulic gradient (ft/mi) I	Width of section (mi) L	Quantity of water available (mgd) Q = TIL	Number of analyses	Range in chemical constituents and properties of ground water (in ppm, except for pH)
Aquia Greensand	+100		Aquifer	20	1,000[2]	10	4	0.2	6 6 6 6	Iron (Fe) 0.07 – 20 Chloride (Cl) 1.5 – 5.4 Hardness as $CaCO_3$ 13 – 66 pH 6.5 – 7.0
Monmouth and Matawan Formations	-100		Aquiclude	–	–	–	–	–		
Magothy and Raritan Formations	Sea level		Aquifer	70	60,000	26	4	6.2	2 2 2 2	Iron (Fe) 2.5 – 16 Chloride (Cl) .8 – 2.5 Hardness as $CaCO_3$ 25 – 42 pH 5.1 – 6.3
	-200		Aquiclude							
	-300		Aquifer	300	20,000[2]	37	4	3.0		
Patapsco Formation	-400 -500		Aquiclude							

	-500, -600, -700	Aquifer	530	16,000[2]	40	4	2.5[2]			
Arundel Clay	-800, -900	Aquiclude								
Patuxent Formation	-1,000, -1,100	Aquifer	950[1]	20,000[2]	56	4	4.5[2]			

[1] Based in part on data from deep wells at Belair in Prince Georges County.

[2] From data at Belair, values estimated from grain-size analysis for Patuxent Formation.

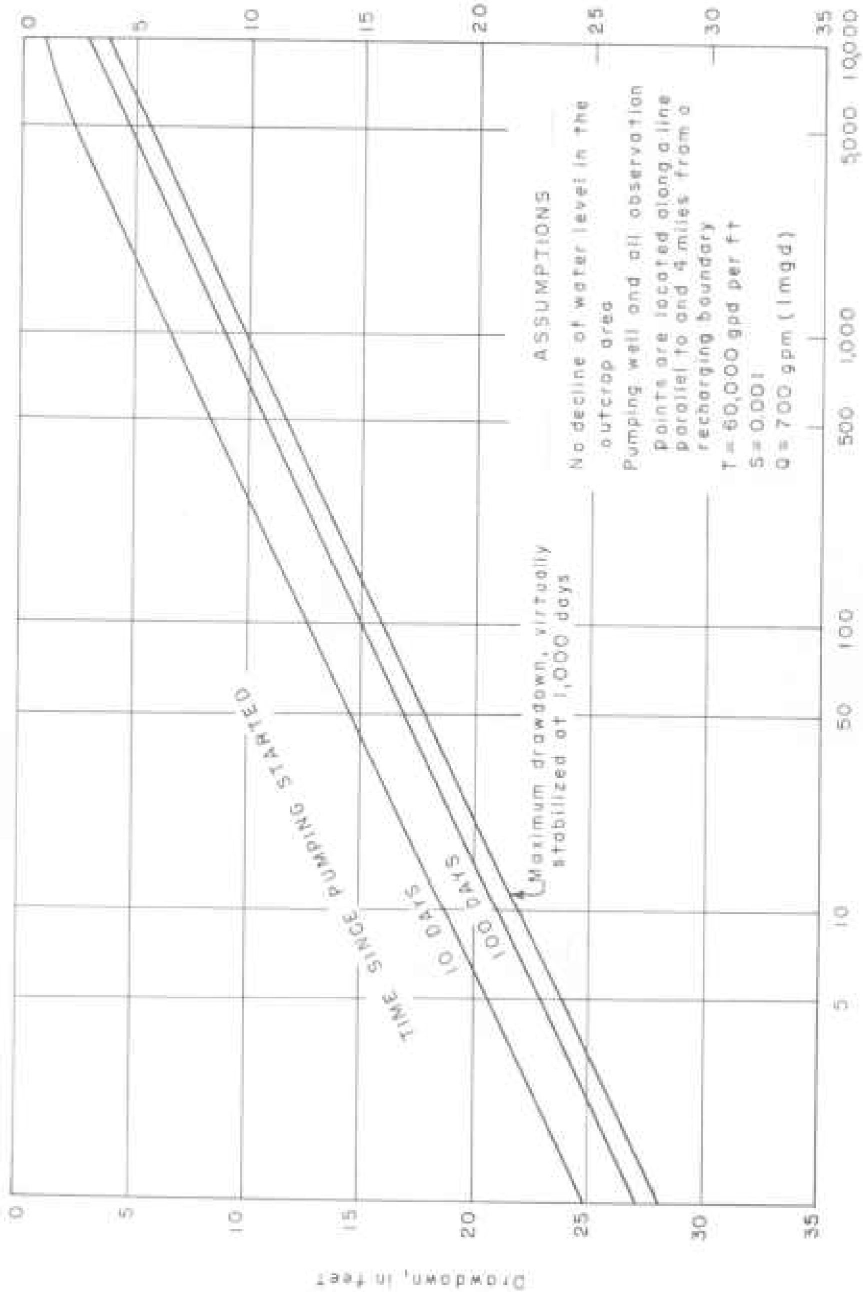

FIGURE 8. Graph Showing Theoretical Declines in Hydraulic Head (Drawdowns) Caused by Pumping from the Aquifer in the Raritan and Magothy Formations in Governor Bridge Area.

The magnitude of the ground-water supplies available in the area was estimated on the assumption that water levels in all the artesian aquifers could be lowered to the top of the aquifer and that the aquifers would then behave as conduits conducting water across an arbitrary 4-mile wide strip. Using the formula $Q = TIL$, the maximum theoretical flow across each strip of aquifer is approximately (from Table 13):

Aquifer	Total flow at assumed maximum hydraulic gradient (mgd)
Aquia Greensand	0.2
Raritan and Magothy Formations	6.2
Patapsco Formation	
(sand at −275 to −385 ft)	3.0
(sand at −500 to −775 ft)	2.5
Patuxent Formation (upper part)	4.5
Total	16.4

The theoretical limit of ground water which could be transmitted across a 4-mile wide strip normal to the strike of the formations is about 16 mgd. Somewhat less than this quantity of water could be obtained, chiefly because of the difficulty involved in creating the necessary hydraulic gradients.

Maryland City

The Maryland City area includes an area of 12 square miles in the westernmost part of the County (Pl. 18). It lies east of Laurel (Prince Georges County) and southeast of U. S. Route 1. The area is underlain by 175 to 200 feet of Coastal Plain strata. Only one aquifer of any importance exists; it is a sand near the base of the Patuxent Formation.

The average use of ground water in the area in 1960 is estimated to have been about 0.1 mgd. It is predicted that by 1980 the water demand may increase to about 0.9 mgd (Lyon, 1961).

Until about 1955, the District Training School, located adjacent to the area, pumped about 0.18 mgd. However, because of the corrosive character of the water, sanding of the wells, and for other reasons, the ground-water supply was abandoned in favor of a connection with the Fort Meade surface-water supply.

The reported yields of the most productive wells in the area range from 60 to 330 gpm; specific capacities range from 1.4 to 9.0 gpm per foot of drawdown (Table 14). The well having the highest yield was drilled to a depth of 223 feet. The well was screened in the basal sand in the Patuxent Formation at an altitude of +19 to +9 feet. Wells in the area yielding more than 300 gpm would be regarded as exceptional.

TABLE 14

Data on High-capacity Wells in the Maryland City Area

Owner	Owner's number	Year drilled	Altitude of land surface (ft)	Depth of well (ft)	Altitude of screen (ft)	Altitude of water level (ft)			Yield (gpm)	Specific capacity (gpm/ft of drawdown)	Aquifer
						Static	Pumping	Date			
Maryland State Fair (Laurel Race Course)	2	1947	144	60	94 to 84	143	134	5/9/47	60	5	Patuxent Formation
Do	1	1947	147	61	96 to 86	143	132	6/16/60	100	9	Do
Do	3	1954	142	62	90 to 80	138	—	6/16/60	100	—	Do
Maryland City	1	1954	130	85	78 to 68	128	73	9/3/54	100	2	Do
Do	2	1954	130	105	83 to 68	123	73	9/7/54	165	3	Do
Do	4	1954	175	125	65 to 50	122	65	9/23/54	300	5	Do
Do	5	1954	195	190	20 to 5	120	15	10/1/54	105	1	Do
Do	7	1957	235	177	68 to 58	137	61	3/1/57	278	4	Do
Do	8	1957	165	104	71 to 61	138	23	3/7/57	315	4	Do
Colony 7 Motel	Test well 1	1960	170	161	19 to 9	130	45	6/30/60	200	2	Do
Do	Test well 2	1960	170	223	−48 to −53	130	30	11/14/60	330	3	Do
Robert Lee Welsh	—	1954	135	145	−5 to −10	111	—	8/23/54	100	—	Do
William B. Barber	—	1956	215	197	37 to 32 23 to 18	97	60	7/16/56	100	3	Do
District Training School	4	1932	110	174	36 to 31 −15 to −20 −36 to −41 −52 to −64	104	74	1932	110	3	Do

Three aquifer tests in the area show a range in the coefficient of transmissibility of from 600 to 15,000 gpd per ft. The test results and an evaluation of their accuracy are:

Aquifer test site	Coefficient of T (gpd/ft)	Accuracy of test
District Training School	600	Fair to poor
Colony 7 Motel	15,000	Good
Laurel Race Course	10,000	Good

A weighted average coefficient of transmissibility of 10,000 gpd per ft was used in Table 15, which presents geologic, hydrologic, and chemical data used to estimate the availability and quality of water in the area.

Well logs in the vicinity of the Patuxent River south of Laurel suggest that a hydrologic connection may exist between the river and the basal sand in the Patuxent Formation (fig. 9), in which case the river would function as a recharge source permitting relatively high hydraulic gradients to be maintained in the sand. Accordingly, the maximum hydraulic gradient (Table 15) would be 100 ft per mile, on the assumption that a hypothetical line of wells tapping a 4-mile wide strip of aquifer would be located 1-mile downdip from a recharging stream. Computations, based on the Theis equation, have shown that wells located near a stream functioning as a line source of recharge to an aquifer, will eventually obtain 95 percent of their water from the stream. Using the formula $Q = TIL$, a transmissibility of 10,000 gpd per foot, a perennial stream as a line source of recharge, and an assumed maximum hydraulic gradient of 100 feet per mile, the theoretical flow across a 4-mile wide strip of aquifer would be:

Aquifer	Total flow at assumed maximum hydraulic gradient (mgd)
Patuxent Formation (basal sand at −100 to −130 ft)	4.0

The estimate of 4 mgd of water available from this aquifer in the Maryland City area must be regarded as a theoretical maximum, limited by the practical difficulties of creating sufficiently steep hydraulic gradients in the aquifer and by the fact that silt or clay in the bed of the Patuxent River may greatly reduce the permeability along the contact between the aquifer and the river.

TABLE 15

Geologic, Hydrologic, and Chemical Data Used in Estimating the Availability and Quality of Ground Water in the Maryland City Area

GEOHYDROLOGY				DATA USED IN COMPUTATIONS					QUALITY OF WATER	
Geologic unit	Position relative to sea level (ft)	Composite geologic section[1]	Aquifer or aquiclude	Available drawdown (ft)	Transmissibility (gpd/ft) T	Maximum hydraulic gradient (ft/mi) I	Width of section (mi) L	Quantity of water available (mgd) Q = TIL	Number of analyses	Range in chemical constituents and properties of ground water (in ppm, except for pH)
Arundel Clay	+200		Aquiclude							
Patuxent Formation	+100		Aquiclude							
			Aquifer	43	10,000	100	4	4.0	3 4 4 4	Iron (Fe) 0.0 – 0.2 Chloride (Cl) 2 – 6.2 Hardness as $CaCO_3$ 2 – 16 pH 5.2 – 6.7
Crystalline Rocks	Sea level		Aquiclude							

[1] Based on log of test well drilled 0.6 mile east of the Patuxent River and 0.5 mile south of Md. Route 602.

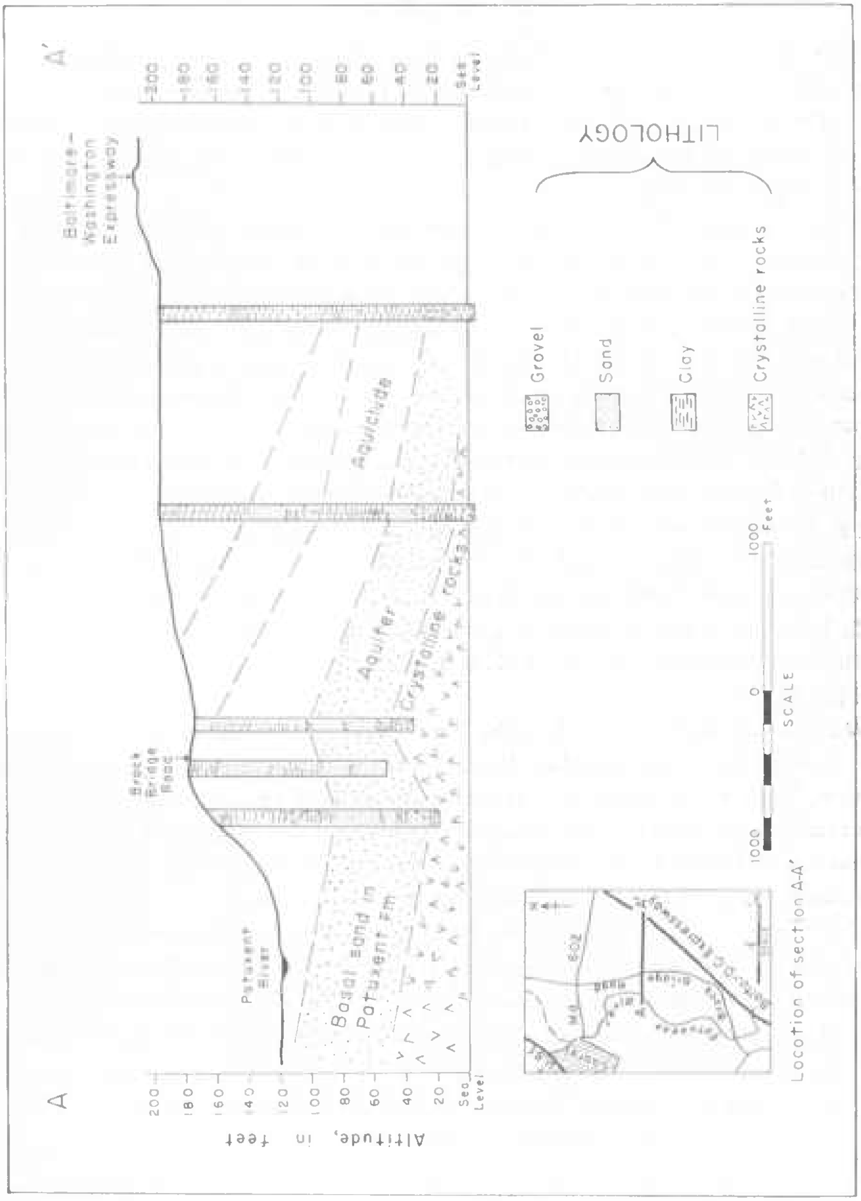

FIGURE 9. Geologic Section Showing the Basal Sand in the Patuxent Formation Where It Extends Beneath the Patuxent River in the Maryland City Area

Mountain Road

The Mountain Road area includes approximately 14 square miles of a peninsula extending into Chesapeake Bay in the northeastern part of the County (Pl. 18). An estimated average of 0.8 mgd of ground water was used in the Mountain Road area in 1960, or about one-third of the predicted water requirements for 1980.

Table 16 summarizes the available geologic, hydrologic, and chemical data for the area. The geologic data are representative of conditions in the southeastern part of the area near Gibson Island. Because the formations dip to the southeast, strata younger than the Patapsco Formation thin toward the northwest and are completely missing in the northern part of the area. Several relatively thin water-bearing sands occur in the Patapsco Formation. Some of these beds grade laterally into sandy clays and silts and cannot be traced for any distance with certainty. The aquifers are variable in permeability and thickness from place to place, and their water-yielding properties vary accordingly. An aquifer test at the well field of the Anne Arundel County Sanitary Commission at Gibson Island shows the coefficient of transmissibility of one of the sands to be 11,000 gpd per foot. By using the specific capacities of a few wells in the area, and by using the general character of the formation, the sum of the transmissibilities of the sands is estimated to be from 20,000 to 25,000 gpd per foot.

Water in the Raritan and Magothy Formations occurs mainly under water-table conditions in the Mountain Road area as it is in the outcrop area of the aquifer. Most of the water in it is derived from local precipitation. In places the available drawdown in the aquifer in the Raritan and Magothy Formations is less than 100 feet. It may be prudent to develop large-diameter wells having low screen losses to obtain high yields per foot of drawdown.

The deepest well in the Mountain Road area is 661 feet deep and does not penetrate the Patuxent Formation, the top of which lies at an estimated depth of 800 to 1,000 feet below sea level (Pl. 5). The appraisal of the available ground-water supply is limited to strata above an altitude of -630 feet (Table 16). Four water-bearing sands whose estimated transmissibilities range from 1,000 to 11,000 gpd per foot occur within the interval from -630 feet to the surface. The maximum hydraulic gradients which could be created in the sands range from 35 to 45 ft per mile. Assuming that the aquifers will function as conduits to transmit the water downdip from their outcrop areas, and using the formula $Q = TIL$, the total flow across each 4-mile wide section of aquifer is estimated to be about 5 mgd (Table 16):

TABLE 16

Geologic, Hydrologic, and Chemical Data Used in Estimating the Availability and Quality of Ground Water in the Mountain Road Area

GEOHYDROLOGY				DATA USED IN COMPUTATIONS					QUALITY OF WATER	
Geologic unit	Position relative to sea level (ft)	Composite geologic section[1]	Aquifer or aquiclude	Available drawdown (ft)	Transmissibility (gpd/ft) T	Maximum hydraulic gradient (ft/mi) I	Width of section (mi) L	Quantity of water available (mgd) Q = TIL	Number of analyses	Range in chemical constituents and properties of ground water (in ppm, except for pH)
Matawan Formation			Aquiclude							
	Sea level		Aquifer	25	1,000[2]	35	4	1.4	3 3 3 3	Iron (Fe) 0.08 – 0.35 Chloride (Cl) 3.0 – 7.0 Hardness as $CaCO_3$ 9 – 25 pH 4.4 – 4.9
Magothy and Raritan Formations	-100		Aquiclude							
			Aquifer	140	5,000[2]	45	4	.9	5 6 6 6	Iron (Fe) .64 – 17 Chloride (Cl) .2 – 6.0 Hardness as $CaCO_3$ 6 – 15 pH 3.8 – 6.1
Patapsco Formation	-200		Aquiclude							
	-300		Aquifer	280	11,000[3]	45	4	2.0	1 1 1 1	Iron (Fe) 6.0 Chloride (Cl) 4.2 Hardness as $CaCO_3$ 16 pH 5.8
	-400		Aquiclude							
			Aquifer	440	5,000[2]	45	4	.9	2 2 2 2	Iron (Fe) 2.5 – 18 Chloride (Cl) 2.0 – 3.0 Hardness as $CaCO_3$ 7 – 16 pH 4.1 – 6.1
	-500 -600		Aquiclude							

[1] Upper 320 feet based on log of well at Gibson Island; section below 320 feet based on well 2 miles north of Gibson Island.

[2] Estimated.

[3] From aquifer test at Gibson Island.

Aquifer	Total flow at assumed maximum hydraulic gradient (mgd)
Raritan and Magothy Formations	
(sand at 0 to −20 ft)	1.4
(sand at −135 to −160 ft)	0.9
Patapsco Formation	
(sand at −280 to −310 ft)	2.0
(sand at −430 to −465 ft)	0.9
Total	5.2

Although the foregoing analysis is based on the behavior of the aquifers as conduits transmitting ground water downdip from the intake areas of the sands, the irregular lenticular character of the sands and the separating clays may provide an opportunity for some of the shallower sands to transmit water to the deeper sands more or less directly from recharge due to precipitation on the Mountain Road area. Based on an approximate rate of ground-water recharge of 0.5 mgd per square mile (p. 13), the 14 square miles designated as the Mountain Road area would receive about 7 mgd of ground-water recharge, which is about 3 times the predicted water demand in 1980 (2.5 mgd). The major problems which may arise in this area regarding the use of ground water will relate to its poor quality and to the hazard of salt-water encroachment into the aquifers, rather than to the lack of availability of ground water.

Odenton-Millersville

The Odenton-Millersville area covers an area of 21 square miles in the central western part of the County (Pl. 18). As the area is located on the main line of the Pennsylvania Railroad between Washington and Baltimore, additional industrial development and rapid population growth is anticipated. Continued industrial development may depend, however, upon the availability of large quantities of water. Predictions based on water use trends in 1960 indicate the water requirement of the area in 1980 may be about 5 mgd (Lyon, 1961), possibly 3 mgd for residential use and 2 mgd for industrial use.

In the Odenton-Millersville area approximately 1.8 mgd of water were pumped during 1960 from sands in the Patapsco Formation. The National Plastic Products Co. used 1.3 mgd, the Kings Heights public-supply system about 0.1 mgd, and private wells about 0.4 mgd.

The yields of large-capacity wells range from 115 to 610 gpm and their specific capacities range from 3 to 12 gpm per foot of drawdown. Table 17 summarizes the pertinent construction and yield data for the important wells in the Odenton-Millersville area.

The aquifers in the area slope toward the southeast. They are about 150

TABLE 17

Data on High-Capacity Wells in or near the Odenton-Millersville Area

Owner	Owner's number	Year drilled	Altitude of land surface (ft)	Depth of well (ft)	Altitude of screen (ft)	Altitude of water level (ft)			Yield (gpm)	Specific capacity (gpm/ft of drawdown)	Aquifer
						Static	Pumping	Date			
National Plastic Products Co.	1	1944	130	166	−16 to −36	79[1]	56[1]	2/1/57	115[1]	5	Patapsco Formation
Do	2	1945	131	180	−15 to −35	77[1]	29[1]	2/3/60	310[1]	6	Do
Do	3	1947	120	168	−26 to −46	72[1]	22[1]	2/3/60	610[1]	12	Do
Do	4	1950	137	185	−16 to −48	72[1]	16[1]	2/3/60	575[1]	10	Do
Do	5	1954	120	155	−5 to −35	66[1]	16[1]	2/3/60	575[1]	12	Do
U. S. Naval Academy Dairy	2	1956	200	269	6 to 1 −40 to −45 −59 to −69	88[1]	49[1]	10/15/56	340[1]	9	Do
Anne Arundel County San. Comm. (Kings Heights supply)	—	1955	178	164	29 to 14	120.8	45	4/21/60	260	4	Do
Do	Test 1	1962	178	872	−674 to −694	72	18	1/16/62	205	4	Patuxent Formation
Do	Test 2	1962	178	727	−529 to −549	72	37	1/19/62	210	6	Do
Do	Test 3	1962	178	458	−260 to −280	76	37	1/25/62	205	5	Patapsco Formation
Do	Test 4	1962	178	298	−100 to −120	79	11	1/30/62	219	3	Do
Fort Meade	Pistol Range	1959	148	Drilled to 615; completed at 238.	−60 to −90	102	50	8/19/59	250	5	Do

[1] Reported by driller.

TABLE 18

Geologic, Hydrologic, and Chemical Data Used in Estimating the Availability and Quality of Ground Water in the Odenton-Millersville Area

GEOHYDROLOGY				DATA USED IN COMPUTATIONS					QUALITY OF WATER	
Geologic unit	Position relative to sea level	Composite geologic section[1]	Aquifer or aquiclude	Available drawdown (ft)	Transmissibility (gpd/ft) T	Maximum hydraulic gradient (ft/mi) I	Width of section (mi) L	Quantity of water available (mgd) Q = TIL	Number of analyses	Range in chemical constituents and properties of ground water (in ppm, except for pH)
Patapsco Formation			Aquiclude							
	+100		Aquifer	97	5,300	35	4	4.7	[illegible]	Iron (Fe) 0.07 Chloride (Cl) 2.2 – 3.3 Hardness as $CaCO_3$ 6 – 36 pH 6.1 – 7.3
	Sea Level		Aquiclude							
	−100		Aquifer	160	30,000	45	4	5.4	5 5 6 6	Iron (Fe) .02 – .4 Chloride (Cl) 1.9 – 9 Hardness as $CaCO_3$ 3 – 18 pH 4.9 – 6.3
	−200		Aquiclude							
	−300		Aquifer	310	20,000	50	4	4.0	[illegible]	Iron (Fe) 1.0 – 3.1 Chloride (Cl) 1.5 – 4.0 Hardness as $CaCO_3$ 3 – 5 pH 4.5 – 6.7

Arundel Clay	-400	Aquiclude								
Patuxent Formation	-500	Aquifer	580	15,000	90	4	5.4	1 1 1 1	Iron (Fe) Chloride (Cl) Hardness as $CaCO_3$ pH	2.7 .0 6 4.9
		Aquiclude								
	-600	Aquifer	645	50,000	90	4	18.0	2 2 2 1	Iron (Fe) Chloride (Cl) Hardness as $CaCO_3$ pH	1.1 – 1.5 2.0 – 2.5 4 – 5 5.2
	-700	Aquiclude								
Crystalline Rocks		Aquiclude								

[1] Based chiefly on log of test well drilled at Kings Heights in 1962.

[2] Static water level is below top of aquifer.

feet lower in altitude in the vicinity of Millersville than they are northwest of Odenton. The Raritan and Magothy Formations are absent at Odenton and are not included in Table 18. In the Millersville area they are about 100 feet thick and yield water to farm and domestic wells.

At Kings Heights near Odenton, the Patuxent Formation has been tested by drilling and pumping from wells of large capacity. The formation here contains two water-bearing sands (Table 18); the deeper sand at an altitude of −575 feet is separated from the shallower sand at an altitude of −510 feet by a moderately thick impervious clay layer. Possibly the two sands are hydrologically connected within a short distance, but the data are inadequate to substantiate this statement. Data from aquifer tests show that the coefficients of transmissibility of the two sands are 50,000 and 15,000 gpd per foot, respectively. Aquifers with these transmissibilities would yield large quantities of water if their hydrologic properties were uniform in all directions. However, in the updip direction (toward the outcrop area) the sands thin and apparently merge, and their transmissibility decreases to about 10,000 gpd per foot. Thus, their capacity to transmit water from the updip recharge area to the Odenton area is substantially reduced. For a relatively short period of time, the high transmissibilities of the sands in the Patuxent Formation at Odenton (Kings Heights) would permit large quantities of water to be withdrawn with a relatively small decline in water levels in the aquifers. Figure 10 shows the theoretical decline in water levels which would occur at observation points up to 10,000 feet away along a line parallel to a recharging boundary on the assumption that pumping will be at a rate of 1 mgd from two sands having transmissibilities totaling 65,000 gpd per foot and an assumed coefficient of storage of 0.0001 extrapolated from an aquifer test at Glen Burnie. Over a long period of time, the drawdowns in the aquifers will be greater than shown in figure 10 because of the lower transmissibilities in the recharge area.

The logs of wells drilled in 1961 at Kings Heights show three separate sands in the Patapsco Formation. The base of the lowermost sand is at an altitude of −330 feet. From the bottom upward their thicknesses are 95, 100, and 120 feet. Based on aquifer tests, their transmissibilities are 20,000, 30,000 and 5,000 gpd per foot, respectively. In 1960 the middle sand in the Patapsco Formation at Odenton (Table 18) yielded nearly all the ground water used. Wells of the National Plastic Products Co., small commercial establishments, and many homes have wells ending in this sand. At the Plastic Products plant the sand is at an altitude of 0 to −100 feet and at the Kings Heights well field it lies at an altitude of −80 to −170 feet. In 1960 pumping levels in wells tapping the aquifer at the Plastics Products plant were only a few feet above the top of the sand, indicating that the rate of withdrawal of water from the sand in the immediate vicinity of the plant cannot be greatly increased. Figure 11 shows the theoretical drawdowns to be expected at distances as great as 10,000 feet

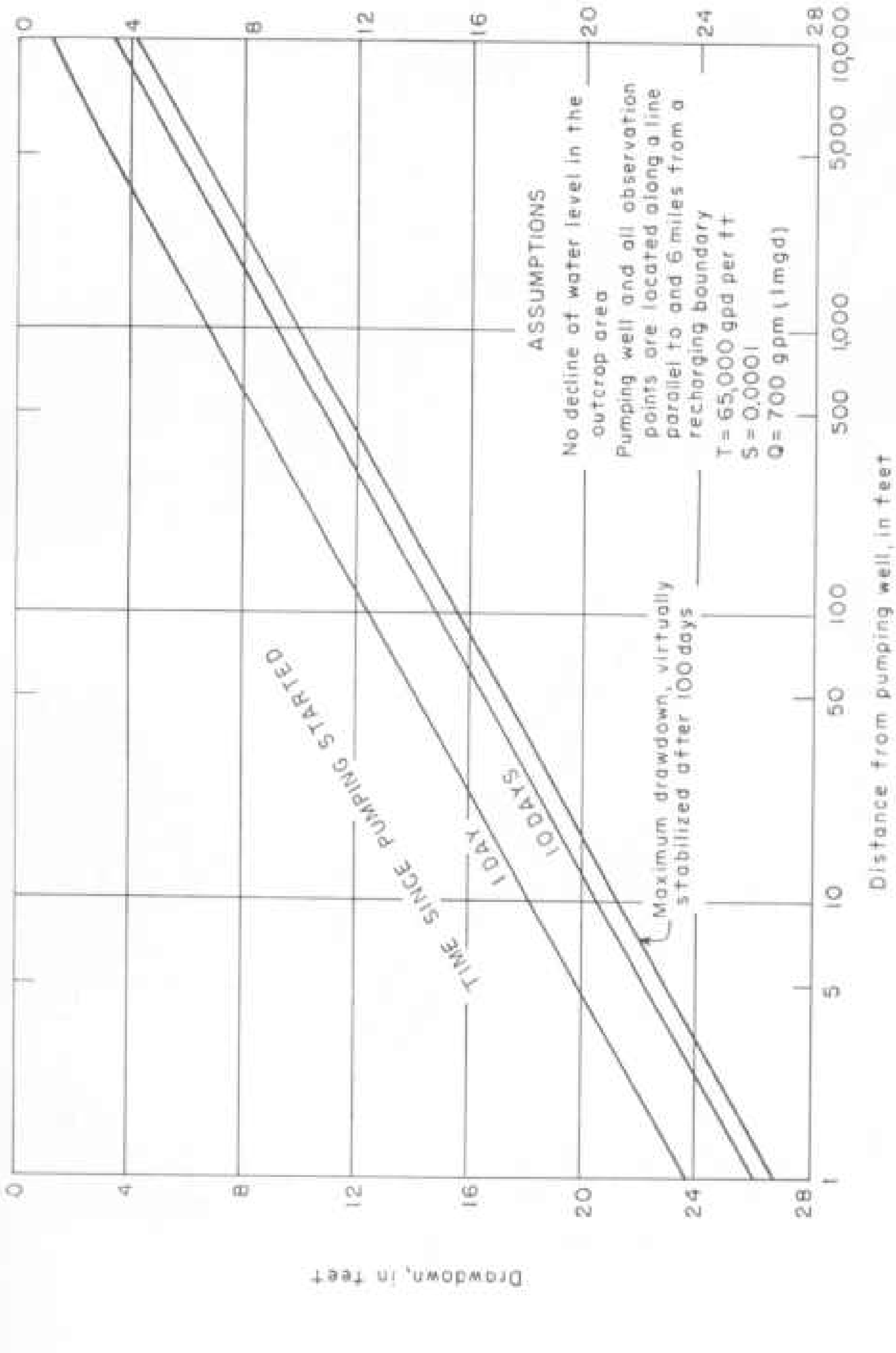

FIGURE 10. Graph Showing Theoretical Declines in Hydraulic Head (Drawdowns) Caused by Pumping from Two Sands in the Patuxent Formation in the Odenton-Millersville Area

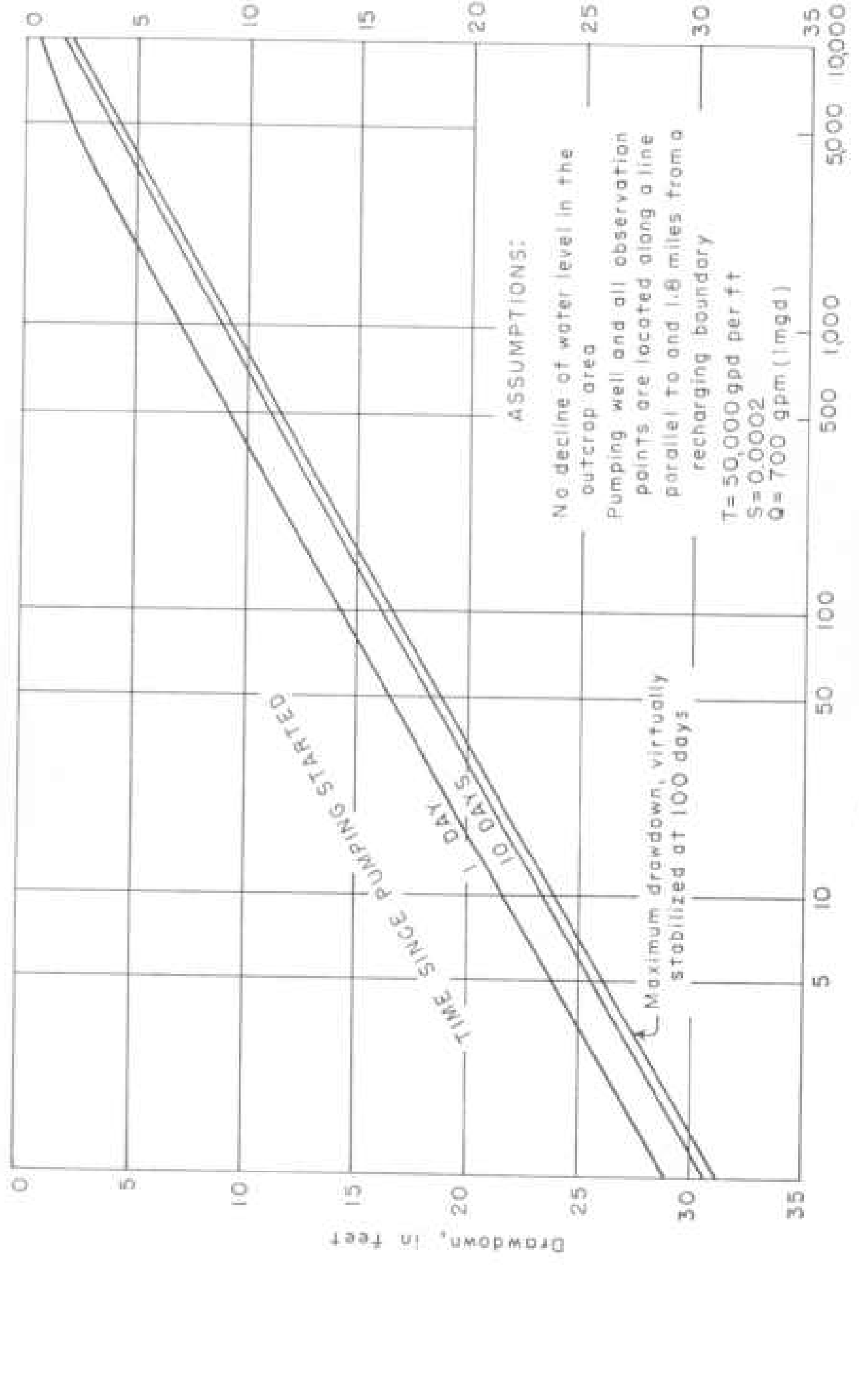

FIGURE 11. Graph Showing Theoretical Declines in Hydraulic Head (Drawdowns) Caused by Pumping from the Two Deepest Sands in the Patapsco Formation in the Odenton-Millersville Area

at observation points along a line parallel to a recharging boundary based on pumping from the two basal sands at a rate of 700 gpm, or 1 mgd. The graph is based on idealized geohydrologic conditions and the assumption that the observation wells will be screened in both the lower and middle sands.

The data in Table 18 make it possible to evaluate the theoretical maximum flow through the artesian aquifers in the Odenton area, assuming that they would function as conduits and transmit water from the intake area across a 4-mile wide strip of aquifer to the withdrawal area. Hydraulic gradients are those obtained by an assumed lowering of water levels to the upper surfaces of the aquifers. Based on the formula $Q = TIL$, the theoretical rate of flow under two different conditions is given. Column A shows the long-term condition in which the transmissibility of the Patuxent Formation near its outcrop area (10,000 gpd per foot) limits the flow of water to the Odenton area through the strip of aquifer. Column B shows the short-term condition (based on the local transmissibility of 65,000 gpd per foot) in which a greater quantity of water would appear to be available from the Patuxent Formation.

Aquifer	Total flow at assumed maximum hydraulic gradient (mgd)	
	A) Limiting value—long term	B) High value—short term
Patapsco Formation		
(sand at +130 to +7 ft)	0.7	0.7
(sand at −70 to −170 ft)	5.4	5.4
(sand at −235 to −330 ft)	4.0	4.0
Patuxent Formation		
(sand at −505 to −545 ft)	3.6[a]	5.4
(sand at −570 to −695 ft)		18.0
Totals	13.7	33.5

[a] Based on transmissibility of 10,000 gpd per foot in outcrop area.

It is doubtful if the hydraulic heads in the aquifers could be lowered sufficiently to create the relatively high hydraulic gradients assumed. Furthermore, the analysis assumes that no declines will occur in the water levels in the aquifers as a result of pumping from the aquifers in the updip or recharge direction.

Wise development of the ground-water resources of the Odenton-Millersville area should be based on the limiting value of 14 mgd, until information is available to indicate that substantial additional development is feasible. More reliable estimates of the available ground-water supplies can be obtained by drilling additional wells, obtaining more data on aquifer properties, and by refining the analysis of the geohydrology by using geomathematical models based on the additional field data.

Broad Neck

The Broad Neck peninsula area covers about 15 square miles in the east-central part of the County along the Revell Highway (Pl. 18). The strata underlying the area have been explored by deep wells to a depth of about 530 feet. An additional 1,000 to 1,300 feet of sedimentary strata may exist below the present limit of drilling.

During 1960, aquifers in the area supplied an average of about 0.9 mgd of water to wells. The largest well fields are located at the U. S. Naval Engineering Experiment Station, at Pines-on-Severn, and at Belvedere Heights. The total daily average pumpage from these three fields was about 0.7 mgd; the remaining 0.2 mgd was from individual domestic and commercial wells, chiefly at Cape St. Claire, Arnold, and St. Margarets. An estimated average of 1.7 mgd of water will be needed in the area by 1980 (Lyon, 1961).

The yield of individual high-capacity wells on the peninsula ranges from 30 to 650 gpm (Table 19). The largest well, at the Naval Engineering Experiment

TABLE 19

Data on High-Capacity Wells in the Broad Neck Area

Owner	Owner's number	Year drilled	Altitude of land surface (ft)	Depth of well (ft)	Altitude of screen (ft)	Altitude of water level (ft)			Yield (gpm)	Specific capacity (gpm/ft of drawdown)	Aquifer
						Static	Pumping	Date			
U. S. Naval Engineering Experiment Station	2	1944	10	600	−470 to −590	flowing	−22	2/27/46	620	<14	Patapsco Formation
Do	3	1948	32	402	−318 to −370	—	—	—	490	—	Raritan Formation
Do	4	1952	80	590	−445 to −495 −500 to −510	15	−40	—	650	12	Patapsco Formation
Pines-on-Severn[1]	1	1959	15	203	−168 to −188	2	−71	10/19/59	440	6	Raritan and Magothy Formations
Do	2	1959	15	416	−381 to −401	5	−61	11/6/59	450	9	Patapsco Formation
Sandy Point State Park	—	1949	10	268	−248 to −258	2	−38	9/10/49	220	5	Magothy Formation
Charterhouse Motel and Restaurant	2	1959	100	128	−23 to −28	33	−25	4/21/59	30	.5	Aquia Greensand

[1] Owned by Anne Arundel County Sanitary Commission.

TABLE 20

Geologic, Hydrologic, and Chemical Data Used in Estimating the Availability and Quality of Ground Water in the Broad Neck Area

GEOHYDROLOGY				DATA USED IN COMPUTATIONS					QUALITY OF WATER	
Geologic unit	Position relative to sea level (ft)	Composite geologic section[1]	Aquifer or aquiclude	Available drawdown (ft)	Transmissibility (gpd/ft) T	Maximum hydraulic gradient (ft/mi) I	Width of section (mi) L	Quantity of water available (mgd) Q = TIL	Number of analyses	Range in chemical constituents and properties of ground water (in ppm, except for pH)
Aquia Greensand	Sea level		Aquifer	33	1,000[2]	.25	8	0.1	13 12 12 14	Iron (Fe) 0.05 – 16 Chloride (Cl) .5 – 12 Hardness as $CaCO_3$ 1 – 28 pH 3.5 – 6.3
Monmouth and Matawan Formations	-100		Aquiclude							
Magothy and Raritan Formations	-200		Aquifer	250	20,000	25	4	2	12 12 11 12	Iron (Fe) 13 – 30 Chloride (Cl) .0 – 1.8 Hardness as $CaCO_3$ 26 – 61 pH 4.1 – 8.2
Patapsco Formation	-300		Aquiclude							
			Aquifer	340	15,000[2]	35	4	2.1	2 2 1 2	Iron (Fe) 8.7 – 11 Chloride (Cl) .0 Hardness as $CaCO_3$ 12 pH 3.4 – 4.3
	-400		Aquiclude							
	-500		Aquifer	400	40,000	40	4	7.2	3 3 3 3	Iron (Fe) 15 – 20 Chloride (Cl) .5 – 1.0 Hardness as $CaCO_3$ 28 – 35 pH 4.1 – 5.1
			Aquiclude							

[1] Based chiefly on log of well 4 at the U. S. Naval Engineering Experiment Station.
[2] Estimated.

Station, contains 60 feet of screen opposite a sand in the Patapsco Formation. This well alone, if it were pumped continuously, would supply the average daily water requirements of the peninsula.

The Patapsco, Raritan, Magothy, and Aquia Formations currently provide the water supply on the Broad Neck peninsula. At least five water-bearing sands occur in a column of strata about 600 feet thick, extending to about 525 feet below sea level (Table 20). Additional untested aquifers are believed to lie below an altitude of −525 feet.

Sands in the Patapsco Formation are among the best aquifers underlying the peninsula. Wells in them have the highest yields and specific capacities. The most permeable sand lies at a depth of 450 to 500 feet below sea level. Because it lies at depth and is overlain by at least three clayey layers, it is probably protected from salt water that might leak downward from the Chesapeake Bay. Aquifer tests at Pines-on-Severn and at the Naval Engineering Experiment Station show that the coefficient of transmissibility of the −450 to −500-foot sand in the Patapsco Formation is 39,000 gpd per foot and 45,000 gpd per foot, respectively. Figure 12, based on data from a test at the Experiment Station, shows the theoretical drawdowns at various distances from a well discharging 1 mgd from the −450 to −500-foot sand in the Patapsco Formation.

Aquifer tests indicate that the aquifer in the Raritan and Magothy Formations has a transmissibility on the order of 20,000 gpd per foot. The top of this aquifer is at sea level on the northern end of the peninsula and slopes gently toward the southeast to an altitude of about 250 feet below sea level at Sandy Point near the Bay Bridge. Because much of the outcrop area of this aquifer lies beneath the Magothy River, heavy pumping from it would probably cause saline water from the river to move downdip to contaminate wells producing from it. The aquifer is particularly vulnerable to this hazard along the north central part of the area.

Plate 15 shows that the artesian head in sands in the Raritan and Magothy Formations is highest near the areas which are highest topographically. Where the piezometric contours close in an upland area, water from the surface must be leaking into the Raritan and Magothy Formations through overlying semipermeable beds. As long as the general direction of movement of water is seaward from the center of the peninsula, it is improbable that saline water will migrate into the aquifer. However, withdrawal of large quantities of water from the aquifer will lower the artesian head below the level of the Bay, cause a reversal of the normal seaward hydraulic gradient, and induce the saline water to move toward the pumping wells.

Heavy pumping from the aquifer in the Raritan and Magothy Formations in the Broad Neck area should be discouraged until a detailed study determines more precisely the magnitude of the hazards of salt-water contamination in it. Further analysis of the problem may show that with proper well location and

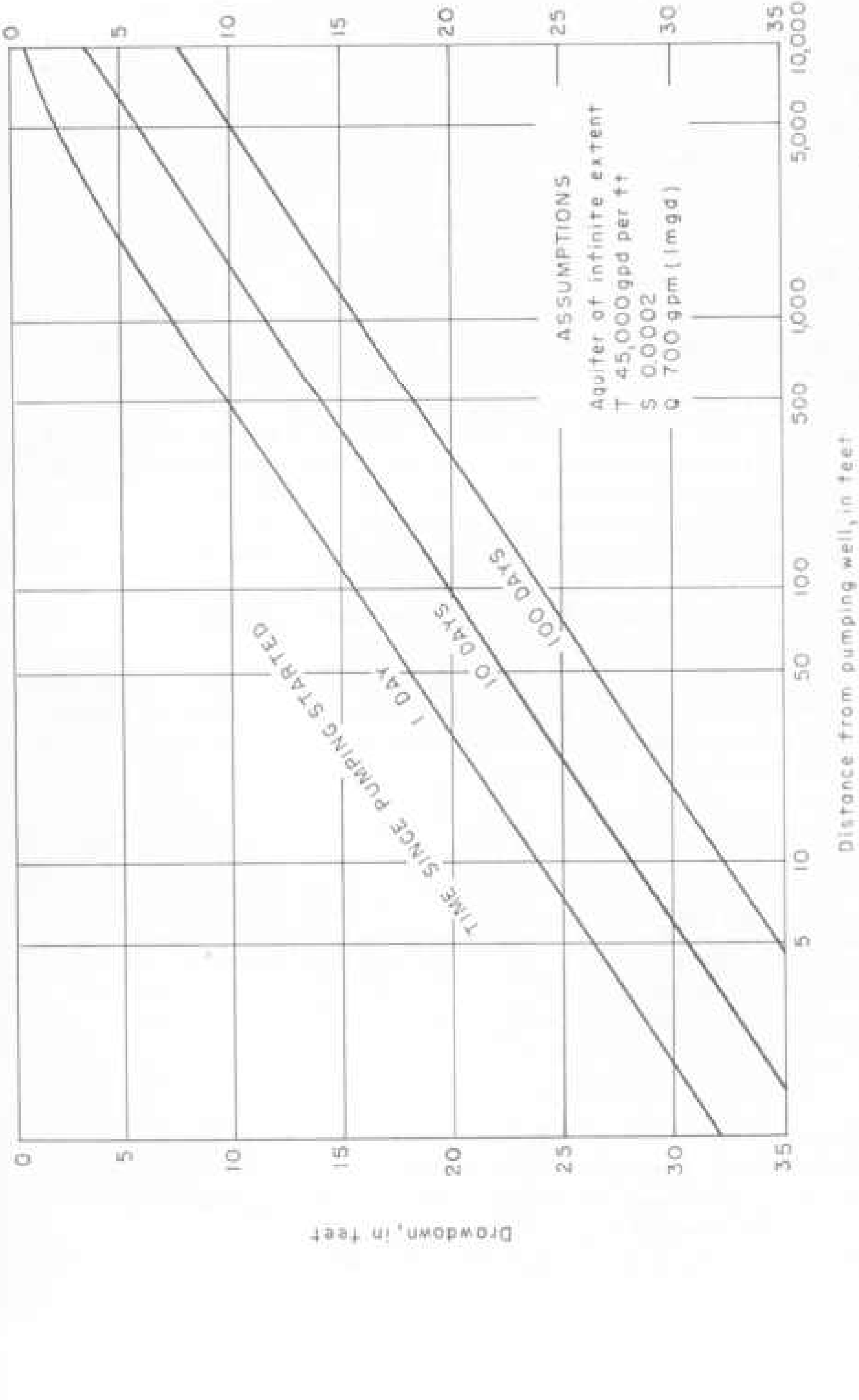

FIGURE 12. Graph Showing Theoretical Declines in Hydraulic Head (Drawdowns) Caused by Pumping from a Sand in the Patapsco Formation in the Broad Neck Area

spacing, additional large quantities of water can be taken from sands in the underlying Patapsco Formation because their sub-outcrop beneath the Bay floor lies at a greater distance from the Broad Neck area than the sub-outcrop of the overlying aquifer in the Raritan and Magothy Formations.

Wells at a military installation near the Revell Highway (U.S. 301), at the Sandy Point State Park, at Pines-on-Severn, and at the Naval Experiment Station are screened in the aquifer in the Raritan and Magothy Formations. Figure 13 shows the theoretical drawdowns to be expected at various distances from a well pumping 1 mgd in the aquifer, based on data obtained from an aquifer test at the Sandy Point State Park.

The Aquia Greensand crops out over most of the Broad Neck peninsula. In the vicinity of the estuaries it is overlain by 30 or 40 feet of sands and clays of Quaternary age. These deposits are unimportant as sources of ground water, but locally the clays create artesian conditions in the greensand.

Domestic and commercial wells of small yield (10 to 40 gpm) supply water for many of the motels, restaurants, and gas stations along Revell Highway and for many of the rural residences throughout the peninsula. Wells yielding more than 100 gpm probably cannot be completed in the Aquia Greensand because much of the formation lies above the water table. Because of the relatively thin zone of saturation, the available drawdown in wells is small and their yields cannot be great. In places the greensand is too clayey or silty to be an aquifer.

Using the concept that the artesian aquifers function as conduits to transmit the ground water downdip from the recharge areas, and using the formula $Q = TIL$, the maximum theoretical flow across each 4-mile wide strip of aquifer is (from Table 20):

Aquifer	Total flow at assumed maximum hydraulic gradient (mgd)
Aquia Greensand (+10 to −30 ft altitude)	0.1
Magothy and Raritan Formations (−140 to −200 ft altitude)	2.0
Patapsco Formation	
(sand at −330 to −370 ft)	2.1
(sand at −450 to −505 ft)	7.2
Total	11.4

The estimate is valid only if it were possible to create hydraulic gradients sufficiently steep to induce the water to flow through the aquifers at the rates indicated. Uniform hydraulic gradients of this magnitude are difficult to attain by means of pumping from wells. Furthermore, extensive heavy pumping from these aquifers in the adjacent Annapolis area would reduce the available

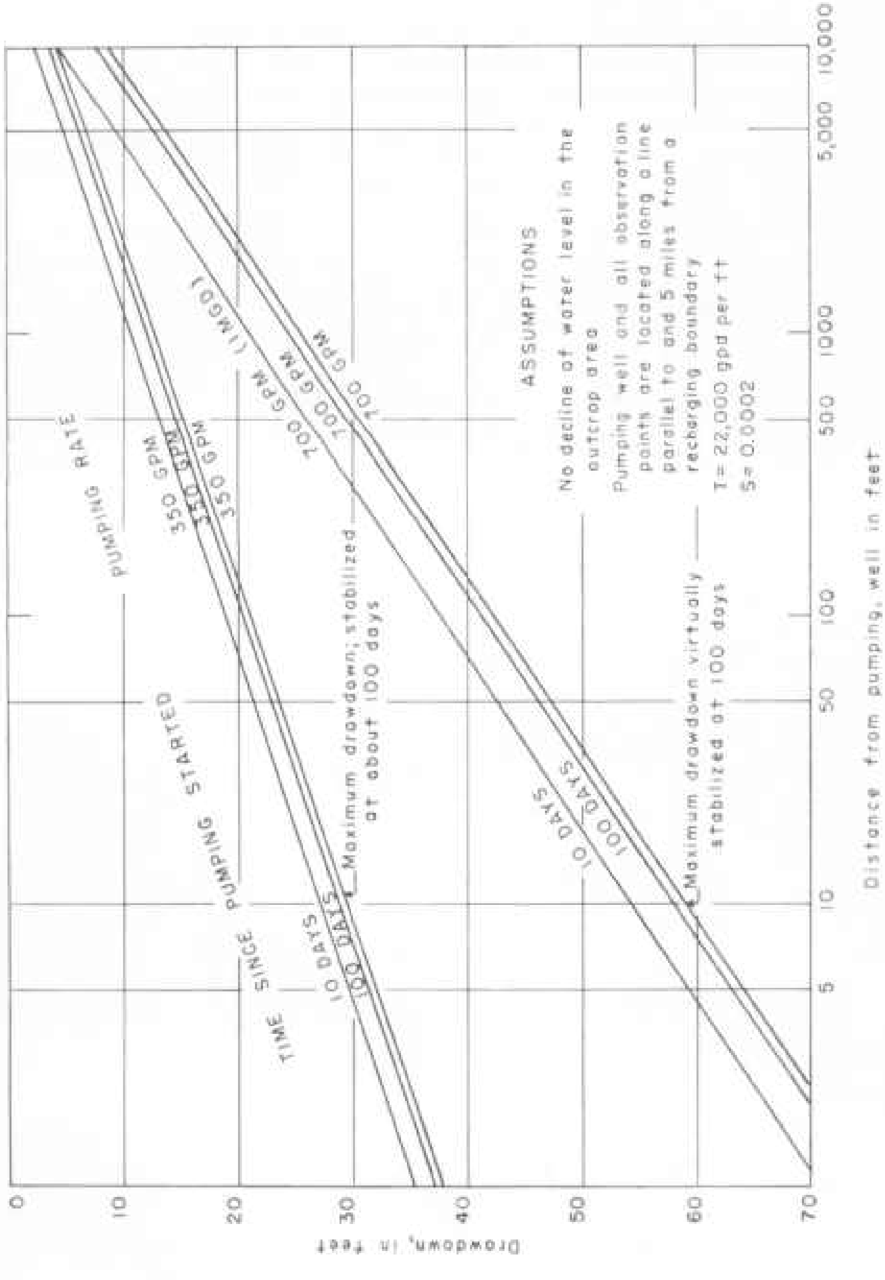

FIGURE 13. Graph Showing Theoretical Declines in Hydraulic Head (Drawdowns) Caused by Pumping from the Aquifer in the Raritan and Magothy Formations in the Broad Neck Area

hydraulic heads in the aquifers and hence the quantity of ground water available in the Broad Neck peninsula. The estimate of 11 mgd fixes an upper limit on the availability of ground water within the part of the geologic column for which information is currently available.

Severna Park-Severndale

The Severna Park-Severndale area includes about 20 square miles along the upper part of the Severn River (Pl. 18). The area is underlain by about 1,000 to 1,200 feet of unconsolidated sedimentary deposits which contain several excellent aquifers. Ground water is the only source of water supply in the area at present.

Wells in the area yielded an estimated average of 0.5 mgd of ground water during 1960. About 0.3 mgd was from the well fields of the Anne Arundel County Sanitary Commission at Severna Park. The remainder was chiefly from domestic and commercial wells of small capacity. The demand for water in the area is predicted to increase to about 1.5 mgd by 1980 (Lyon, 1961).

Most of the ground-water supplies in the area are obtained from a few

TABLE 21

Data on High-Capacity Wells in the Severna Park-Severndale Area

Owner	Owner's number	Year drilled	Altitude of land surface (ft)	Depth of well (ft)	Altitude of screen (ft)	Altitude of water level (ft)			Yield (gpm)	Specific Capacity (gpm/ft of drawdown)	Aquifer
						Static	Pumping	Date			
Anne Arundel County Sanitary Commission (Severna Park)	1	1950	10	119	−99 to −109	10+[1]	—	1950	155[1]	—	Patapsco Formation
Do	2	1954	10	185	−165 to −175	9[1]	−50[1]	8/19/54	174[1]	3	Do
Do	3	1959	10	150	−120 to −140	0[1]	−38[1]	7/30/59	350[1]	9	Do
Anne Arundel County Sanitary Commission (Severndale)	Test well 1	1960	80	602	−455 to −470	22	−45	5/12/60	328	5	Do
Do	Test well 2	1960	80	218	−128 to −138	18	−65	5/25/60	259	3	Do
Do	do	1960	80	490	−357 to −367 −400 to −410	21	—	6/11/60	304	—	Do
Do	1	1961	80	550	−450 to −470	19[1]	−36[1]	9/16/61	500[1]	9	Do
Do	2	1961	80	508	−352 to −362 −418 to −428	21[1]	−21[1]	8/23/61	500[1]	12	Do
Do	3	1961	80	198	−103 to −118	17[1]	−45[1]	10/19/61	400[1]	7	Do

[1] Reported by driller.

TABLE 22

Geologic, Hydrologic, and Chemical Data Used in Estimating the Availability and Quality of Ground Water in the Severna Park-Severndale Area

GEOHYDROLOGY				DATA USED IN COMPUTATIONS					QUALITY OF WATER	
Geologic unit	Position relative to sea level (ft)	Composite geologic section[1]	Aquifer or aquiclude	Available drawdown (ft)	Transmissibility (gpd/ft) T	Maximum hydraulic gradient (ft/mi) I	Width of section (mi) L	Quantity of water available (mgd) Q = TIL	Number of analyses	Range in chemical constituents and properties of ground water (in ppm, except for pH)
Magothy and Raritan Formations	Sea level		Aquifer						6 6 6 6	Iron (Fe) 0.08 – 8.1 Chloride (Cl) 1.2 – 7.0 Hardness as $CaCO_3$ 9 – 37 pH 3.5 – 5.9
Patapsco Formation	−100		Aquiclude							
	−200		Aquifer	170	11,000	25	4	1.1	8 9 5 8	Iron (Fe) 0.07 – 5.8 Chloride (Cl) 1.0 – 64 Hardness as $CaCO_3$ 2 – 27 pH 3.9 – 5.2
	−300		Aquiclude							
	−400		Aquifer	330	40,000	30	4	4.8	2 2 2 2	Iron (Fe) 0.7 – 1.5 Chloride (Cl) .5 – 7.0 Hardness as $CaCO_3$ 4 – 5 pH 4.3 – 4.8
	−500		Aquiclude							

[1] Based chiefly on log of test well drilled at Severndale in 1960.

excellent water-bearing sands in the Patapsco Formation. The yields of large-capacity wells tapping these aquifers range from 155 to 350 gpm; specific capacities of the wells range from 3 to 12 gpm per foot of drawdown (Table 21). The deepest well is screened in a sand in the Patapsco Formation at an altitude of −455 to −470 feet. In 1960 the available drawdown in this well, based on a static water-level altitude of +22 feet, was about 360 feet.

Table 22 shows two thick water-yielding aquifers in the Patapsco Formation and another aquifer in the Magothy and Raritan Formations from the land surface to altitudes of −20 or −30 feet. At Severndale the deeper aquifer in the Patapsco Formation is separated by about 20 feet of sandy clay into a lower sand at an altitude of −450 to −470 feet and an overlying sand at an altitude of −335 to −430 feet. Water-level measurements during an aquifer test showed that the two sands are hydrologically connected and they are, therefore, considered as one aquifer. The transmissibility of the deeper aquifer in the Patapsco Formation is on the order of 40,000 gpd per foot. The transmissibility of the shallower aquifer, from −100 to −210 feet altitude, is about 11,000 gpd per foot.

The aquifer in the Magothy and Raritan Formations, being the uppermost aquifer in the Severna Park-Severndale area is the source of water for many shallow wells. The aquifer was not tested by pumping so its hydrologic characteristics are not known. In many localities only a small proportion of it is saturated, and hence the available drawdown in wells in it is limited. Therefore, this aquifer is not included in the discussion regarding the availability of ground water.

The data in Table 22 permit an analysis of the theoretical maximum rate of flow in the artesian aquifers in their function as conduits. It is assumed that pumping would be limited to drawdowns which would cause the water levels to decline only to the approximate tops of the aquifers, thus establishing maximum permissible hydraulic gradients. Using the modified Darcy formula $Q = TIL$, and the transmissibilities as given, theoretical limiting rates of flow across a 4-mile wide strip of the aquifers are:

Aquifer	Total flow at assumed maximum hydraulic gradient (mgd)
Patapsco Formation	
(sand at −100 to −210 ft)	1.1
(sand at −335 to −470 ft)	4.8
Total	5.9

Additional ground water presumably is available from the deeper untested strata, chiefly the Patuxent Formation. The presence of brackish water in the upper reaches of the Severn River estuary, combined with the permeable, sandy character of the Patapsco and Raritan Formations, suggests that heavy pumping from the aquifers where they lie above an altitude of −200 ft will induce brackish water to move into them where the cone of depression, resulting from such pumping, would reverse the natural flow of ground water into the estuary. Until further study is made of the geohydrology of the area, it would be advisable to restrict withdrawals of ground water on the order of 0.1 mgd or greater to aquifers known to be effectively sealed by clayey strata from brackish surface waters.

Shady Side-Deale

The Shady Side-Deale area (Pl. 18) includes about 24 square miles in the southeastern part of the County. About 16 square miles of the area is land and the remainder is water.

The area is underlain by an estimated 2,000 to 2,500 feet of sedimentary strata, but no wells are known to have been drilled beyond depths of a few hundred feet. Nearly all the ground water used in 1960 was from domestic or commercial wells ending in the Aquia Greensand at altitudes of −225 feet or above. The estimated average pumpage by all users in 1960 was about 0.2 mgd; the total predicted demand in 1980 will be about 0.6 mgd (Lyon, 1961). As the area is largely rural, only a few large-capacity wells have been completed in the greensand. Nearly all the larger wells have been drilled for schools for which the water demand is small compared with industrial or public-supply requirements. Probably none of the wells in current use provide a reliable index of the maximum yield available from the aquifers. The yields of wells range from 40 to 250 gpm, and specific capacities range from 0.5 to 3 gpm per foot of drawdown (Table 23). The best well (Deale Elementary School) has only 5 feet of screen opposite a permeable zone in the Aquia Greensand. The well is 6 inches in diameter and contains a gravel envelope.

Because the layers of sand in the Aquia Greensand resist caving or crumbling, small-diameter wells developed in it for domestic supplies commonly are finished as open holes without screens. An aquifer test at the Galesville Elementary School showed that the coefficient of transmissibility of the Aquia Greensand is about 13,000 gpd per foot.

No wells are known to penetrate the underlying Magothy Formation in the area. Data from nearby wells at Lothian (Southern High School) and at Sunderland (Mount Hope Elementary School) in Calvert County indicate that the Magothy is an aquifer in the area. Geohydrologic information on the Magothy Formation in Table 24 is from the deep well at Lothian, where an aquifer test yielded a coefficient of transmissibility of 6,300 gpd per foot.

The conduit analysis was used to approximate the theoretical limit of available ground-water supplies in the Shady Side-Deale area. Because of the

TABLE 23

Data on High-Capacity Wells in or near the Shady Side-Deale Area

Owner	Owner's number	Year drilled	Altitude of land surface (ft)	Depth of well (ft)	Altitude of screen (ft)	Altitude of water level (ft)			Yield (gpm)	Specific capacity (gpm/ft of drawdown)	Aquifer
						Static[1]	Pumping	Date			
Galesville Elementary School	—	1960	18	142	−119 to −124	1	−42	12/12/60	136	3	Aquia Greensand
Tracys Landing Elementary School	—	1961	140	321	−176 to −181	8	−80	2/22/61	40	.5	Do
Deale Elementary School	—	1961	5	185	−175 to −180	1	−82	1/18/61	250	3	Do
Lula Scott Elementary School (Shady Side)	—	1954	8	137	no screen	1	—	1/-/54	100	—	Do
Southern High School (Lothian)	2	1949	168	575	−373 to −393	29	—	8/22/51	200	—	Magothy Formation

[1] Water levels reported by driller for most wells.

clayey nature of the surficial Pleistocene and Recent deposits, artesian conditions prevail in the aquifers below depths of a few tens of feet, although the area of recharge to the Aquia Greensand lies only a mile or two northwest. Using the formula $Q = TIL$, and assuming that maximum hydraulic gradients could be created, the maximum theoretical flow across each 6-mile wide strip of aquifer is (Table 24):

Aquifer	Total flow at assumed maximum hydraulic gradient (mgd)
Aquia Greensand (sand from −90 to −210 ft)	1.4
Magothy Formation (sand at −350 to −360 ft)	.9
Total	2.3

Because of its greater transmissibility the Aquia Greensand may provide most of the available ground water in the area. However, because of the presence of numerous brackish-water estuaries in the Shady Side-Deale area, the cone or cones of depression which would be created by heavy pumping from the greensand might induce salt water to move into it and eventually migrate into areas now underlain by fresh water. The magnitude and immediacy of this hazard is governed partly by the thickness and uniformity of the silt or clay

TABLE 24

Geologic, Hydrologic, and Chemical Data Used in Estimating the Availability and Quality of Ground Water in the Shady Side-Deale Area

GEOHYDROLOGY				DATA USED IN COMPUTATIONS					QUALITY OF WATER	
Geologic unit	Position relative to sea level (ft)	Composite geologic section[1]	Aquifer or aquiclude	Available drawdown (ft)	Transmissibility (gpd/ft) T	Maximum hydraulic gradient (ft/mi) I	Width of section (mi) L	Quantity of water available (mgd) Q = TIL	Number of analyses	Range in chemical constituents and properties of ground water (in ppm, except for pH)
Pleistocene	Sea level		Aquiclude							
Nanjemoy Formation			Poor Aquifer							
Aquia Greensand	-100 -200		Aquifer	100	13,000	18	6	1.4	8 8 7 8	Iron (Fe) 0.5 – 1.4 Chloride (Cl) 1.0 – 4.0 Hardness as $CaCO_3$ 126 – 185 pH 7.4 – 8.2
Monmouth and Matawan Formations	-300		Aquiclude							
Magothy Formation			Aquifer	360	6,300[2]	25	6	.9	1 1 1 1	Iron (Fe) 15 Chloride (Cl) 2.0 Hardness as $CaCO_3$ 100 pH 6.6

[1] Upper 205 feet based on log of well drilled in 1961 at Deale Elementary School; section below 205 feet based on log of well at Southern High School.

[2] From aquifer test at Southern High School.

TABLE 25

Data on High-capacity Wells in or Near Steuart Corner-Woodland Beach Area

Owner	Year drilled	Altitude of land surface (ft)	Depth of well (ft)	Altitude of screen (ft)	Altitude of water level (ft)[1]			Yield[1] (gpm)	Specific capacity (gpm/ft of draw-down)	Aquifer
					Static	Pump-ing	Date			
Edgewater Elementary School	1952	23	94	−52 to −67	9	−6	5/28/52	60	4	Aquia
Col. C. E. Duval Southdown Shores	1958	30	65	−35	10	−10	5/28/58	25	1	Do
Sylvan Shores Services Co., Inc.	1956	60	325	−253 to −265	18	−50	4/17/56	240	4	Magothy

[1] Reported by driller.

layer commonly present on the floor of the estuaries. Where clays or silts form an extensive, impervious cover over the aquifer, the rate of entrance of brackish water will be substantially retarded or reduced. Accordingly, the 1.4 mgd of ground water available from the greensand must be withdrawn at the risk of causing salt-water contamination into it. It might, therefore, be prudent to develop the major part of the ground water from the underlying Magothy Formation or from unexplored aquifers below the Magothy.

Steuart Corner-Woodland Beach

The Steuart Corner-Woodland Beach area includes about 9 square miles on the south side of the South River in the east central part of the County (Pl. 18). The area is underlain by an estimated 1,200 to 1,500 feet of Coast Plain deposits, but no wells are known to have been drilled below an altitude of −265 feet.

Lyon (1961) predicted that 0.4 mgd of water will be required in the area by 1980, which is about three times greater than the estimated ground water use of 0.15 mgd in 1960. Nearly all the ground-water supplies are obtained from domestic or small-capacity public-supply wells at depths of less than 150 feet.

Only a relatively few wells of large capacity have been constructed in the area. Table 25 summarizes the data for three of the most productive wells. The best well was drilled for the Sylvan Shores Services Co. in 1956. This well, screened in the Magothy Formation at an altitude of −253 to −265 feet, yielded 240 gpm with a specific capacity of 4 gpm per foot of drawdown. The yields of the wells in Table 25 are only roughly indicative of the maximum available yield from the aquifers. The small available drawdown in the Aquia Greensand (about 75 to 100 feet) does, however, restrict the amount of water that can be pumped from it and yields greater than 200 gpm per well should not be expected.

TABLE 26

Geologic, Hydrologic, and Chemical Data Used in Estimating the Availability and Quality of Ground Water in the Stewart Corner-Woodland Beach Area

GEOHYDROLOGY				DATA USED IN COMPUTATIONS					QUALITY OF WATER	
Geologic unit	Elevation relative to sea level (ft)	Composite geologic section	Aquifer or aquiclude	Available drawdown (ft) T	Transmissibility (gpd/ft) T	Maximum hydraulic gradient (ft/mi) I	Width of section (mi) L	Quantity of water available (mgd) Q = TIL	Number of analyses	Range in chemical constituents and properties of ground water (in ppm)
Pleistocene			Aquiclude							
Aquia Greensand	Sea level		Aquifer	15	8,000[2]	10	3	0.4	8 8 8 8	Iron (Fe) 0.3 – 1.4 Chloride (Cl) 1.5 – 8.0 Hardness as $CaCO_3$ 28 – 109 pH 5.5 – 7.9
Monmouth and Matawan Formations	-100		chiefly Aquiclude							
Magothy and Raritan Formations	-200		Aquifer	185	9,000[3]	21	3	.7		
			Aquiclude							
			Aquifer	240	7,000[3]	25	3	.5	1 1 1 1	Iron (Fe) 13 Chloride (Cl) 1.0 Hardness as $CaCO_3$ 94 pH 6.7

[1] Based on data from a well of Sylvan Shores Services Co., Inc.
[2] Estimated from specific capacity of well at Edgewater Elementary School.
[3] Estimated from data from wells at City of Annapolis Water Plant.

Using the data in Table 26 and the formula $Q = TIL$, the theoretical maximum ground-water flow across a 3-mile wide strip of aquifer is:

Aquifer	Total flow at assumed maximum hydraulic gradient (mgd)
Aquia Greensand (water-bearing zone from −5 to −60 ft)	0.4
Magothy and Raritan Formations	
(sand from −180 to −200 ft)	0.7
(sand from −235 to −260 ft)	0.5
Total	1.6

The theoretical rate of flow of 1.6 mgd is based on the assumption that water levels (hydraulic heads) could be lowered to the top of the aquifers, and that the effect of pumping in adjacent areas, as at Annapolis, would not be great enough to cause a lowering of water levels in the Steuart Corner-Woodland Beach area. The above analysis does not include the addition of ground water available from sands in the Patapsco and Patuxent Formations at altitudes below −260 feet which might increase by several times the estimate of ground-water supplies available in the area.

Chemical Character of the Water

BY

CLAIRE A. RICHARDSON

The various minerals and gases with which ground water comes in contact, either in the atmosphere or in the rocks, determine its chemical character. Water is in its purest natural form when it is falling through the atmosphere as rain or snow. As soon as it begins to move through soil and rock, it dissolves some of the mineral matter and thus acquires a different character.

Most ground water can be used for some purpose, but some of it is too highly mineralized to be used for a specific purpose. The U. S. Public Health Service (1961) has established criteria to be applied to water used on interstate carriers. Drinking water preferably should not contain higher concentrations of chemical constituents than are given in these standards. In actual practice, water containing much greater concentrations of some constituents and properties is used without ill effect. In places in Anne Arundel County, ground water is unable to fulfill the water quality standards of the Public Health Service without treatment. Table 27 lists some of the most common chemical constituents in ground water and indicates their significance.

The chemical character of ground water from each aquifer in the areas of special interest is described briefly in the discussion of the area. The range in concentration is given for each of the four major properties and constituents: iron, chloride, hardness, and pH. Ranges of the properties and constituents throughout the entire County are given in the sections describing the individual constituents.

All values are expressed in ppm (parts per million by weight). One part per million is a unit weight of a constituent in a million unit weights of water.

Silica

The silica content of 91 samples of ground water from Anne Arundel County ranges from 1.0 to 56 ppm. Median values of silica content for 72 samples from the Patuxent, Patapsco, and Raritan and Magothy Formations are 9.3, 7.9 and 9.4 ppm, respectively; the median value of water in 19 samples from the Aquia Greensand is 18 ppm. Most natural waters contain less than 30 ppm of silica and only seven analyses from Anne Arundel County show greater concentrations than this. The silica content of ground water in the County should not be troublesome for most uses of the water.

Aluminum

The aluminum content of 37 samples ranges from 0.00 to 3.9 ppm. The median value is 0.0, and only 5 samples show concentrations greater than 1

TABLE 27

Elements and Substances Commonly Found in Ground Water (from Walker, 1956)

Constituent	Source	Significance
Silica (SiO_2)	Siliceous minerals present in essentially all formations.	Forms hard scale in pipes and boilers. Inhibits deterioration of zeolite-type water softeners.
Iron (Fe)	The common iron-bearing minerals present in most formations.	Oxidizes to a reddish-brown sediment. More than about 0.3 ppm stains laundry and utensils reddish brown, is objectionable for food processing, beverages. Larger quantities impart taste and favor the growth of iron bacteria.
Manganese (Mn)	Manganese-bearing minerals.	Rarer than iron; in general has same objectionable features; brown to black stain.
Calcium (Ca) and magnesium (Mg)	Minerals that form limestone and dolomite and occur in some amount in almost all formations. Gypsum also a common source of calcium.	Cause most of the hardness and scale-forming properties of water; soap consuming.
Sodium (Na) and potassium (K)	Feldspars and other common minerals; ancient brines, sea water; industrial brines and sewage.	In large amounts, cause foaming in boilers, and other difficulties in certain specialized industrial water uses.
Bicarbonate (HCO_3) carbonate (CO_3)	Action of carbon dioxide in water on carbonate minerals.	In combination with calcium an magnesium forms carbonate hardness; decomposes on application of heat with attendant formation of scale and release of corrosive carbon dioxide gas.
Sulfate (SO_4)	Gypsum, iron sulfides, and other rarer minerals; common in waters from coal-mining operations and many industrial wastes.	Sulfates of calcium and magnesium form hard scale.
Chloride (Cl)	Found in small to large amounts in all soils and rocks; natural and artificial brines, sea water, sewage.	Objectionable for various specialized industrial uses of water.
Fluoride (F)	Various minerals of wide-spread occurrence, in minute amounts.	In water consumed by children about 1.5 ppm and more may cause mottling of the enamel of teeth, and as much as 1.5 ppm reduces incidence of tooth decay.
Nitrate (NO_3)	Decayed organic matter, sewage, nitrate fertilizers, nitrates in soil.	Values higher than the local average may suggest pollution. More than about 45 ppm NO_3 may cause methemoglobinemia (infant cynosis), which is sometimes fatal. Waters of high nitrate content should not be used for baby feeding (Maxey, 1950).

ppm. The higher values are for waters from the Cretaceous Formations. Values greater than 1 ppm are rare, but may be encountered where the water is acid, as it is in most parts of the County.

Iron

The U. S. Public Health Service recommends that drinking water contains no more than 0.3 ppm of iron (1961, p. 941). Although water containing as much as 100 times this amount of iron has no toxic effect, concentrations of only a few parts per million are troublesome, giving rise to so-called "red water". In Anne Arundel County, high iron concentrations are one of the chief ground-water problems relating to quality of water.

Plate 19 shows the location of wells from which the water was analyzed for iron content. The iron content of 192 samples of ground water in the County ranges from 0.00 to 32 ppm. The range and median value for iron in water from each of the major aquifers are:

Formation	Number of samples	Range in concentration (ppm)	Median (ppm)
Aquia Greensand	50	0.01–32	0.56
Raritan and Magothy	46	.04–30	8.5
Patapsco	77	.00–20	.35
Patuxent	19	.00–3.7	.87

The tabulation shows the wide range of iron concentration in the ground water and the presence of troublesome amounts of iron in the major aquifers. Although the median value of 0.35 ppm for the Patapsco Formation is very near the recommended maximum, the upper limit of concentration indicates that ground water from this aquifer commonly must be treated in order to be of satisfactory quality. In the Glen Burnie area, water from the Patapsco Formation is low in iron (median value 0.04 ppm), and in the public supply it is mixed with water from the underlying Patuxent Formation in order to improve its overall quality. However, water from the Patapsco Formation in the Annapolis area, is higher in iron (median value 18 ppm) than that from the Raritan and Magothy Formations and the Aquia Greensand.

Manganese

The U. S. Public Health Service has set the limit of manganese content in potable water at 0.05 ppm (1961, p. 941). The manganese content of 69 samples from Anne Arundel County ranges from 0.00 to 0.43 ppm. Median values for the various aquifers range from 0.02 to 0.12 ppm. The values conform to the norm for most natural waters. Although the occurrence of manganese in ground water is similar to that of iron, available data indicate that excessively high concentrations of this element do not occur in the ground waters of Anne Arundel County.

Chromium

Only three samples of ground water from the County were analyzed for chromium. These values are all 0.00 ppm. Under normal weathering conditions, little of the element chromium goes into solution, and hence it is unusual to find more than traces of it in natural waters, unless industrial wastes are present. According to standards set by the U. S. Public Health Service (1961), potable water should contain no more than 0.05 ppm of hexavalent chromium.

Lithium

The lithium content of 19 samples of ground water from Anne Arundel County ranges from 0.0 to 0.4 ppm. Little is known of the occurrence of this element in ground water. Lithium-bearing rocks are rare, so low concentrations are to be expected.

Sulfate

The sulfate content of 135 samples of ground water from Anne Arundel County ranges from 0.0 to 70 ppm. The range and median value for each of the major aquifers are:

Formation	Number of samples	Range in concentration (ppm)	Median (ppm)
Aquia Greensand	38	0.2–61	5.5
Raritan and Magothy	37	.0–63	25
Patapsco	50	.0–70	6.6
Patuxent	10	.6–7.5	5.7

All values for sulfate are far below the recommended maximum of 250 ppm, even though there is a considerable range in its concentration. The source of sulfate in the waters of the County probably is due to the natural occurrence of gypsum, a calcium sulfate mineral.

Chloride

Chloride occurs in small amounts in most ground water. In sea water, chloride is one of the chief mineral constituents. In a coastal area, such as Anne Arundel County, where salt water is in direct contact with the water-bearing formations, salt-water intrusion can occur. Such contamination can be induced by pumping either from fresh-water aquifers that outcrop immediately beneath the salt water or from those that lie beneath other sediments that are pervious enough to permit the downward movement of salt water. Once an aquifer is contaminated by salt water, additional pumping from the aquifer may cause the contaminated zone to move inland to previously uncontaminated areas. This movement would depend upon the rate of pumping, the artesian head, and other factors.

The chloride content of 194 ground-water samples from Anne Arundel County ranges from 0.0 to 665 ppm; only five samples (about 3 percent) contain more than 17 ppm. The median value for the four major aquifers is about 2.5 ppm, indicating that the normal chloride content of ground water in the County is far below the recommended maximum of 250 ppm. Two of the five analyses showing above-average chloride concentrations (40 and 86 ppm, respectively) also show high concentrations of nitrate, suggesting that the wells are polluted.

Two analyses of ground water from the County show that salt-water contamination exists in local areas. A sample of water from a well at Sandy Point contained 146 ppm of chloride and a sample from a well at Thomas Point contained 665 ppm of chloride. Both wells are located in low-lying areas near the shoreline of the Chesapeake Bay. The brackish water may have entered the wells either by: a) flooding of the land surface by brackish water during storms; or b) by intrusion into the aquifer from the Chesapeake Bay; or c) by vertical leakage through improperly sealed casings. Although salt-water intrusion is not widespread in the County, it does exist in the adjacent Curtis Bay area of Baltimore City, where the ground water contains chloride in concentrations as high as several hundred ppm (Bennett and Meyer, 1952, p. 124–157).

Plate 20 shows the chloride concentration of water in or near the County both for ground waters and bodies of surface water. The surface-water data from the Chesapeake Bay and its tributaries are from publications of the Chesapeake Bay Institute of The Johns Hopkins University.

Fluoride

Excessively high concentrations of fluoride in drinking water cause mottling of teeth and changes in bone structure. The safe limit is not universally agreed upon, but the Public Health Service recommends control limits between 0.8 and 1.7 ppm (1961, p. 943). Some fluoride in drinking water is a deterrent to tooth decay. Fluoride has been added to the drinking-water supplies of some municipalities in order to combat dental caries. The ground water of Anne Arundel County contains far less fluoride than the recommended maximum concentration.

The fluoride content of 80 ground-water samples from the County ranges from 0.0 to 0.5 ppm. The median value is 0.1 ppm. Only three samples showed a concentration higher than 0.3 ppm; these samples were taken from two wells ending in the Raritan and Magothy Formations in the Annapolis area.

Nitrate

Most nitrogen occurs as a gas in the earth's atmosphere; some occurs on the earth itself in various minerals and in plants. A high concentration of nitrate in ground water can be caused by repeated use of plant fertilizers or by contact with the wastes of warm-blooded animals, thereby becoming an end product of organic pollution.

The nitrate content of 132 ground-water samples from the County ranges from 0.0 to 191 ppm. The median value is 0.2, and 70 percent of the values are less than 1.0 ppm. Only ten samples show values as high as 10 ppm or more.

Water from only three wells contained nitrate in excess of the 44 ppm recommended as the maximum (Hem, 1959, p. 239). Water containing a nitrate content greater than 44 ppm is believed to cause infant cyanosis or "blue-baby" disease.

Phosphate

Although phosphate is necessary for plant growth, the amount found in natural waters generally is small. However, as it is used in detergents, it occurs in higher concentrations in sewage effluent. Above-normal concentrations may serve as an indicator of pollution.

Samples of water from 28 wells in Anne Arundel County were analyzed for phosphate. The phosphate content of these samples ranges from 0.00 to 0.32 ppm. The median value is 0.01 ppm, a very low concentration of this anion.

Hardness

Degrees of hardness of water are recognized by the amount of soap needed to produce a good lather and by the amount of scale formed by heating the water. Water is designated accordingly as "hard" or "soft" water. Calcium and magnesium are the chief causes of hardness, which is expressed in equivalent parts per million of calcium carbonate. In the concentrations found at many places in Anne Arundel County, iron and manganese cause hardness. A commonly used scale for classifying hard or soft water is:

0–60 ppm	Soft water
61–120 ppm	Moderately soft to moderately hard water
121–200 ppm	Hard water
over 200 ppm	Very hard water

Hardness was determined in 173 samples of ground water from the County. The values range from 1.0 to 610 ppm. The ranges and median values for the major aquifers are:

Formation	Number of samples	Range in concentration (ppm)	Median (ppm)
Aquia Greensand	48	1–610	84
Raritan and Magothy	40	3–171	34
Patapsco	68	3–149	12
Patuxent	17	1–204	5

The median values for each aquifer indicate that the water is soft or moderately soft. Plate 21 shows the location of wells for which hardness determinations were made and the hardness of water from each well. In general, the ground water north of Annapolis is soft; the few anomalous values represent water that is either polluted or contaminated from local sources. South of Annapolis most ground water is moderately hard to very hard. Water from the Patuxent and Patapsco Formations commonly is soft. Water from the Raritan and Magothy Formations and the Aquia Greensand is generally soft in the outcrop area but increases in hardness as it moves downdip in the aquifers. Locally, the water from individual wells may be polluted and relatively hard.

pH

The term "pH" is used to express the acidity or alkalinity of water, and represents the hydrogen-ion concentration. A pH of 7.0 is neutral. Water having a pH less than 7.0 indicates increasing acidity; that having a pH greater than 7.0 indicates increasing alkalinity. Acid water is objectionable chiefly for its corrosive attack on metal.

The pH of 195 ground-water samples from Anne Arundel County ranges from 3.2 to 8.2. The ranges and median values for the principal aquifers are:

Formation	Number of samples	Range in concentration (ppm)	Median (ppm)
Aquia Greensand	49	5.0–8.2	6.9
Raritan and Magothy	45	3.2–7.4	5.8
Patapsco	82	3.4–7.3	5.1
Patuxent	19	4.5–6.7	5.4

Plate 22 shows the locations of wells for which pH determinations were made and the values for each water sample. With few exceptions, alkaline ground water is found only south of the South River and this is mostly from the Aquia Greensand.

SUMMARY

The Patuxent, Patapsco, Raritan and Magothy Formations, the Aquia Greensand, and the Pleistocene deposits are the only geologic units in Anne Arundel County containing water-bearing sands capable of supplying ground water in quantities large enough for industrial, municipal, or irrigation supplies. Water in the aquifers occurs under both artesian and water-table conditions. To estimate the amount of ground water available from them where artesian conditions prevail, they were considered to function as conduits. Computations were made of the quantities of water that might be transmitted downdip through them under the hydraulic gradients which would prevail if water levels in them could be lowered to their upper surfaces along a line parallel to their strike. These quantities are:

Formation	Width in miles	Quantity (mgd)
Aquia Greensand	20	5
Raritan and Magothy	25	27
Patapsco	27	25
Patuxent	29	25
Total		82

The quantity of 82 mgd of ground water available from the artesian aquifers must be considered only an approximation of the right order of magnitude. The analysis used to compute this quantity assumes a relatively high degree of uniformity of the physical properties of the aquifers and aquicludes. It further assumes an approximate 100 percent recovery of the ground water by means of wells. In some places actual conditions no doubt deviate substantially from the idealized assumptions used in the analysis.

In addition to the above quantity considered to be available from the artesian aquifers, a very substantial additional quantity of water is available from the aquifers where they occur under water-table conditions. Water-table conditions prevail throughout most of the County and the total outcrop area of the aquifers is substantial. In the outcrop areas the artesian aquifers are brim full and the excess ground-water recharge above that which moves downdip through them maintains the flow of the surface streams. To assess this situation on a quantitative basis the outcrop area of the major aquifers was determined from the geologic map, an approximate rate of recharge was assumed, and, based on the conduit analysis, a subtraction made of the quantities of water which might be transmitted downdip through the artesian aquifers. The residual after subtraction of the maximum theoretical artesian flow is assumed to be the quantity of ground water which could be extracted (or pumped) in the outcrop areas of the major aquifers. This is the water which now flows into the surface streams as ground-water discharge, but which would be in excess of that needed to replenish the artesian flow when and where maximum rates of artesian flow would prevail. The problem is complicated by the fact that a major portion of the outcrop area of some of the artesian aquifers is in adjacent counties. For example, less than 10 percent of the outcrop area of the Patuxent Formation lies in Anne Arundel County.

Table 28 summarizes the estimates of assumed ground-water recharge in the outcrop areas of each of the major aquifers and presents the method of estimating the residual quantity of ground water available for withdrawal in the outcrop areas. Table 28 shows that the recharge in the outcrop areas of the artesian aquifers is approximately 250 mgd (Column F). Subtracting 80 mgd of artesian flow from 250 mgd leaves a balance of approximately 170 mgd (Column J).

Of this quantity only about 100 mgd (Column H) is recharge occurring within Anne Arundel County, and hence to be considered part of the ground-water resources of the County. As a practical matter drawdowns in wells are limited in the water-table areas to a few tens of feet and therefore yields of conventional drilled wells cannot be large. To obtain the maximum quantity of water available in the water-table areas, vertical wells of extra large diameter or horizontal collector-type wells would be required; special types of screens may also be needed. The cost of such wells would be prohibitive for many users. It is believed that only about 50 percent of the ground-water recharge is recoverable by present methods.

Thus, the estimated quantitity of available ground water in Anne Arundel County is 80 mgd of artesian water plus 50 mgd of water-table water, a total of 130 mgd, or about 9 times the approximately 14 mgd used in the County in 1960.

Favorable areas for prospecting for shallow ground-water supplies are the outcrop areas of the major artesian aquifers in the northern half of the County. Substantial shallow ground-water supplies, on the order to several million gallons a day, also may be obtained from water-table wells along the valley of the Patuxent River as far south as latitude 38° 50′.

The saline waters of the Chesapeake Bay are a potential source of contamination for aquifers occurring near it or its estuaries. Thus, hazards of salt-water intrusion exist in much of the eastern part of the County. No significant cases of such intrusion have been recorded in the County, but they do exist on the north side of the Patapsco River at Sparrows Point and on the south side at the Curtis Bay and Fairfield areas in Baltimore City. Further study of the problem will undoubtedly reveal that properly designed, located, and managed well fields can safely take large quantities of ground water from

TABLE 28

Summary of Estimated Ground-Water Recharge to Aquifers in Anne Arundel and Adjacent Counties

Aquifer or geologic unit	Outcrop area of aquifer (sq mi)			Assumed recharge in outcrop area of aquifers (mgd)[1]			Maximum theoretical artesian flow (mgd)	Recharge in excess of that needed to supply the artesian aquifers if the maximum theoretical artesian flow were to occur. (mgd)		
	Anne Arundel County	Adjacent counties	Total	Anne Arundel County	Adjacent counties	Total		Anne Arundel County	Adjacent counties	Total
Column	A	B	C	D	E	F	G	H[2]	I[3]	J[4]
Pleistocene deposits	60	0	60	30	0	30	0	30	0	30
Aquia Greensand	65	45	110	32	23	55	5	29	21	50
Raritan and Magothy Formations	70	8	78	35	4	39	27	11	1	12
Patapsco Formation	85	55	140	42	28	70	25	27	18	45
Patuxent Fortion	10	110	120	5	55	60	25	3	32	35
Total	290	218	508	144	110	254	82	100	72	172

[1] Based on an assumed average rate of recharge of 0.5 mgd per square mile.
[2] $H = D - (A/C \times G)$
[3] $I = E - (B/C \times G)$
[4] $J = F - G$

aquifers in tidewater areas. However, it would be dangerous to develop large-yielding wells in such areas before such studies have been made. Overpumping of shallow aquifers in the Broad Neck and Annapolis areas may not only contaminate the shallow aquifers but may also endanger the deeper aquifers through vertical leakage in improperly sealed and cased wells.

The quantity of ground water available for use in the County can be enhanced by the adoption of conservation measures such as the artificial recharge of aquifers. Methods of doing this have been described by Todd (1959, p. 251–277) and others. Recharge wells have been used since 1957 at the Two Guys Shopping Center near Glen Burnie to return water used for air conditioning to the source aquifer, a sand in the Patapsco Formation. When large amounts of water are needed, this technique makes it possible to use the cooling properties of ground water without substantially reducing the net amount available. Another technique, used for many years on Long Island in New York, uses storm runoff to recharge the aquifers. Collecting basins catch the runoff at times of heavy precipitation and permit the water to infiltrate into the ground during intervals between precipitation.

The quality of ground water in the aquifers commonly varies from one area to another and from one aquifer to another in the same area. Most ground water from the County can be used for some purposes with no treatment, but much of it is too highly mineralized to be used for other purposes without treatment. Median concentrations for the important constituents or properties of water from each of the major aquifers of the County are:

Formation	Hardness (ppm)	pH	Iron (ppm)
Aquia Greensand	84	6.9	0.56
Raritan and Magothy	34	5.8	8.55
Patapsco	12	5.1	.35
Patuxent	5	5.4	.87

These data show that:

1) Water from the Aquia Greensand is moderately hard whereas water from the other aquifers is soft.

2) Water from the Aquia Greensand is nearly neutral whereas water from the other aquifers is more acid in character.

3) Iron concentrations are above the recommended limit of 0.3 ppm in most water from all the aquifers. Iron content appears to be especially high in the Cretaceous aquifers in the east central part of the County (Pl. 19).

The quantity of ground water used is increasing rapidly in some areas and thus decreasing the availability in those and in nearby areas. Changes in the pattern of ground-water use should be observed, recorded, and interpreted as they take place. Essential to this are the measurement of water-level fluctuations in key observation wells and the measurement of the amount of water pumped from large-capacity public-supply and industrial wells.

New geologic and hydrologic data should be collected, organized, and interpreted as they become available in order to provide a continuing record to be used in planning the development of additional ground-water supplies.

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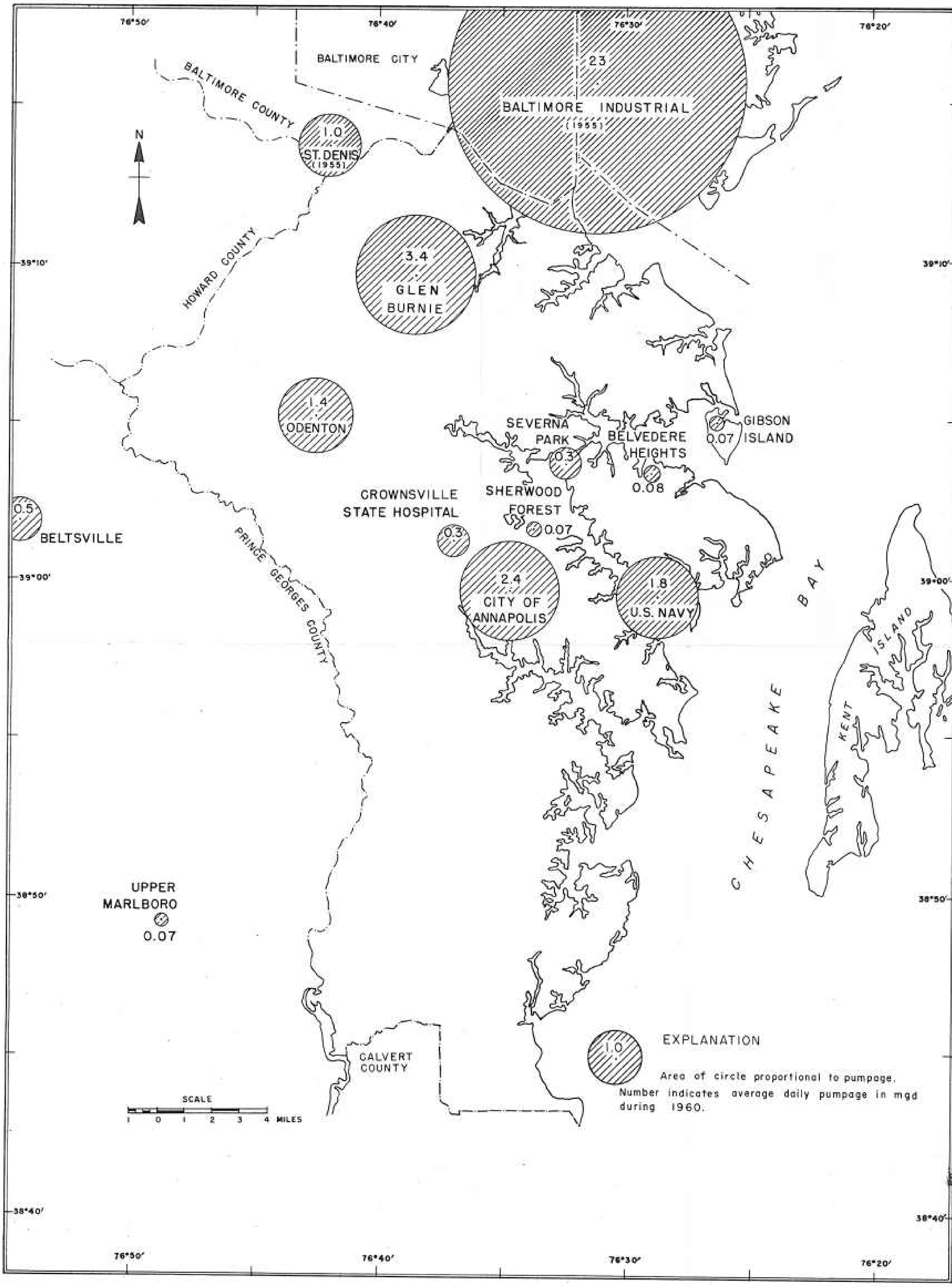
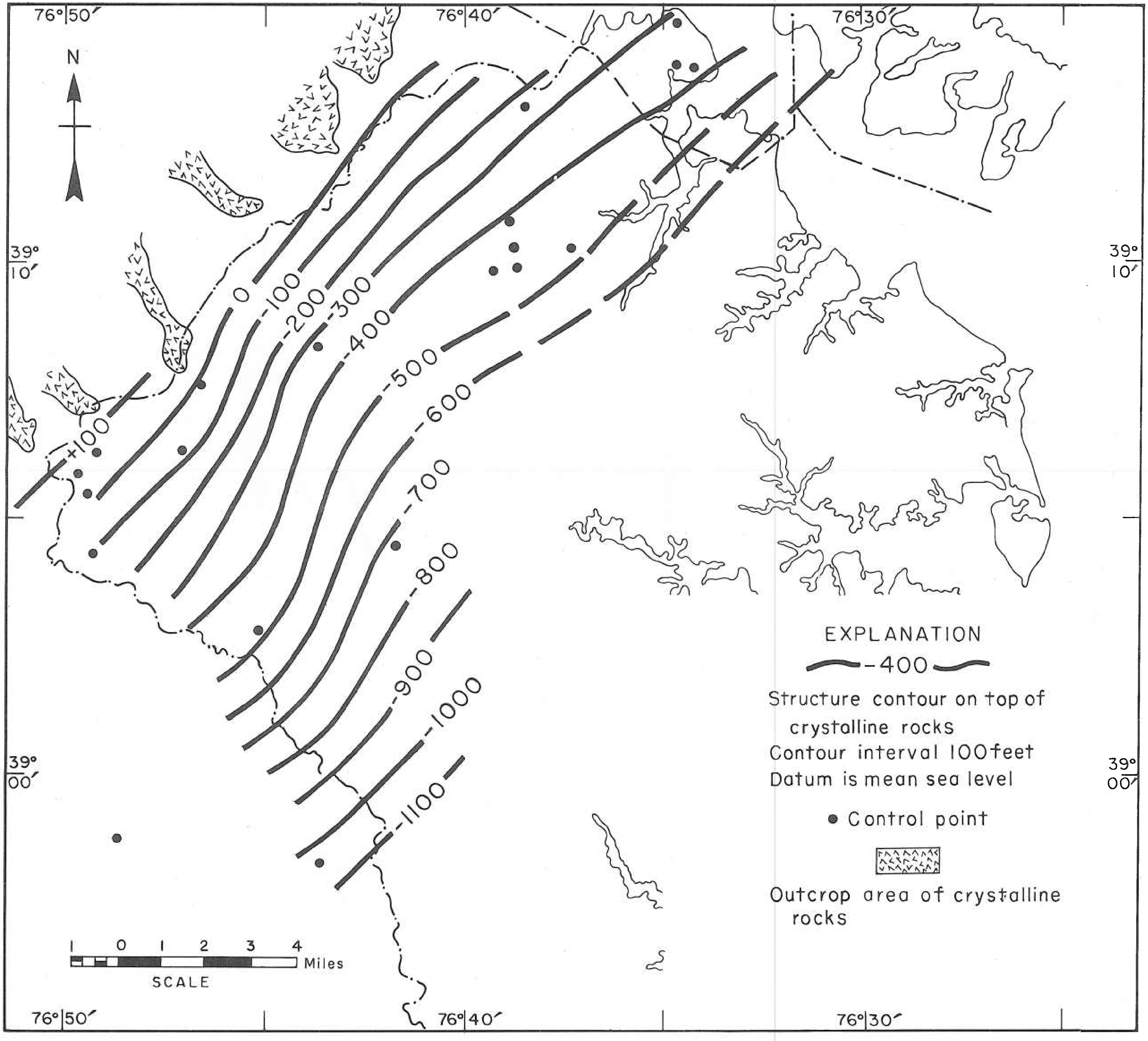
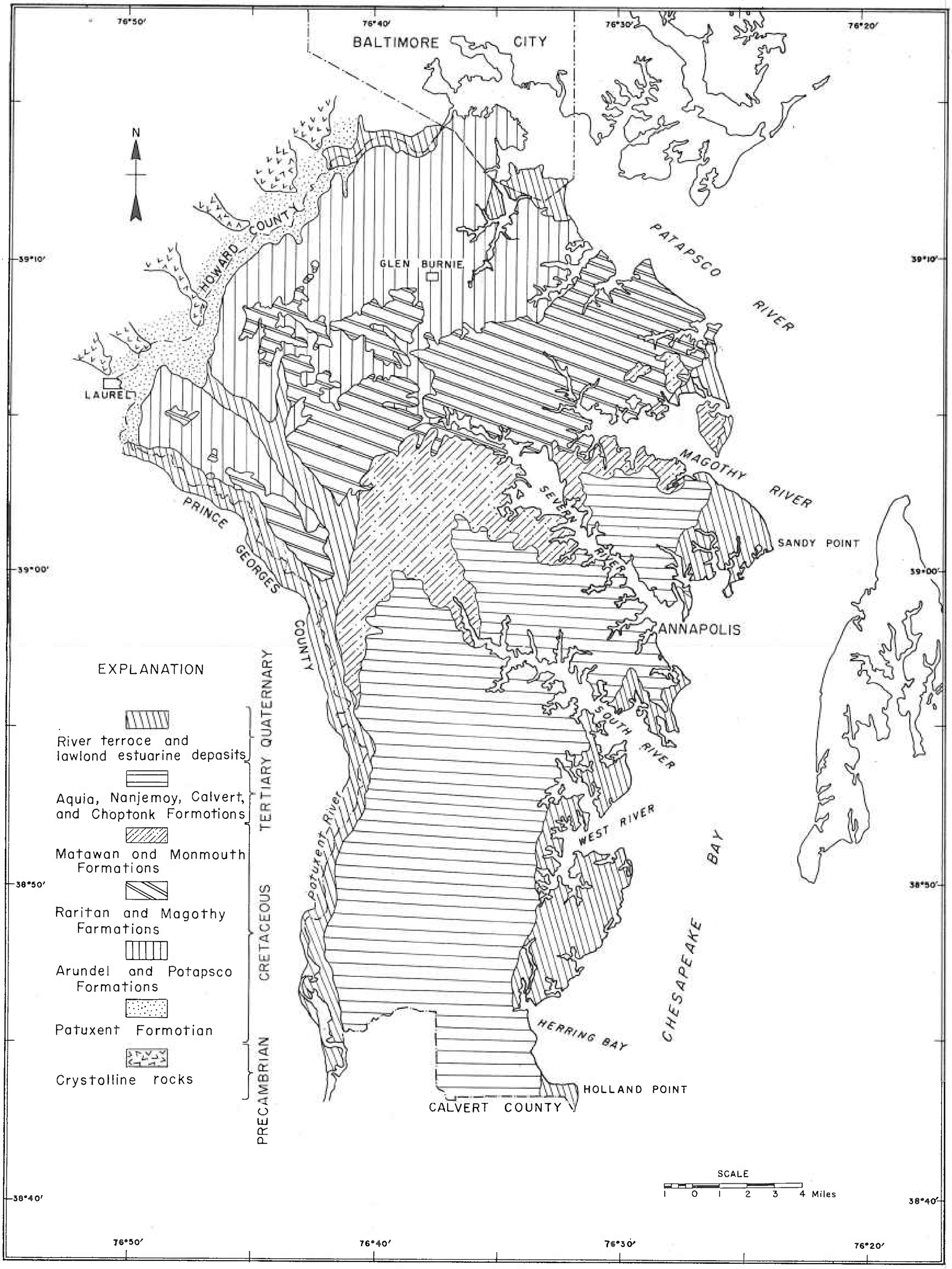
Detailed descriptions are in **boldface** type.



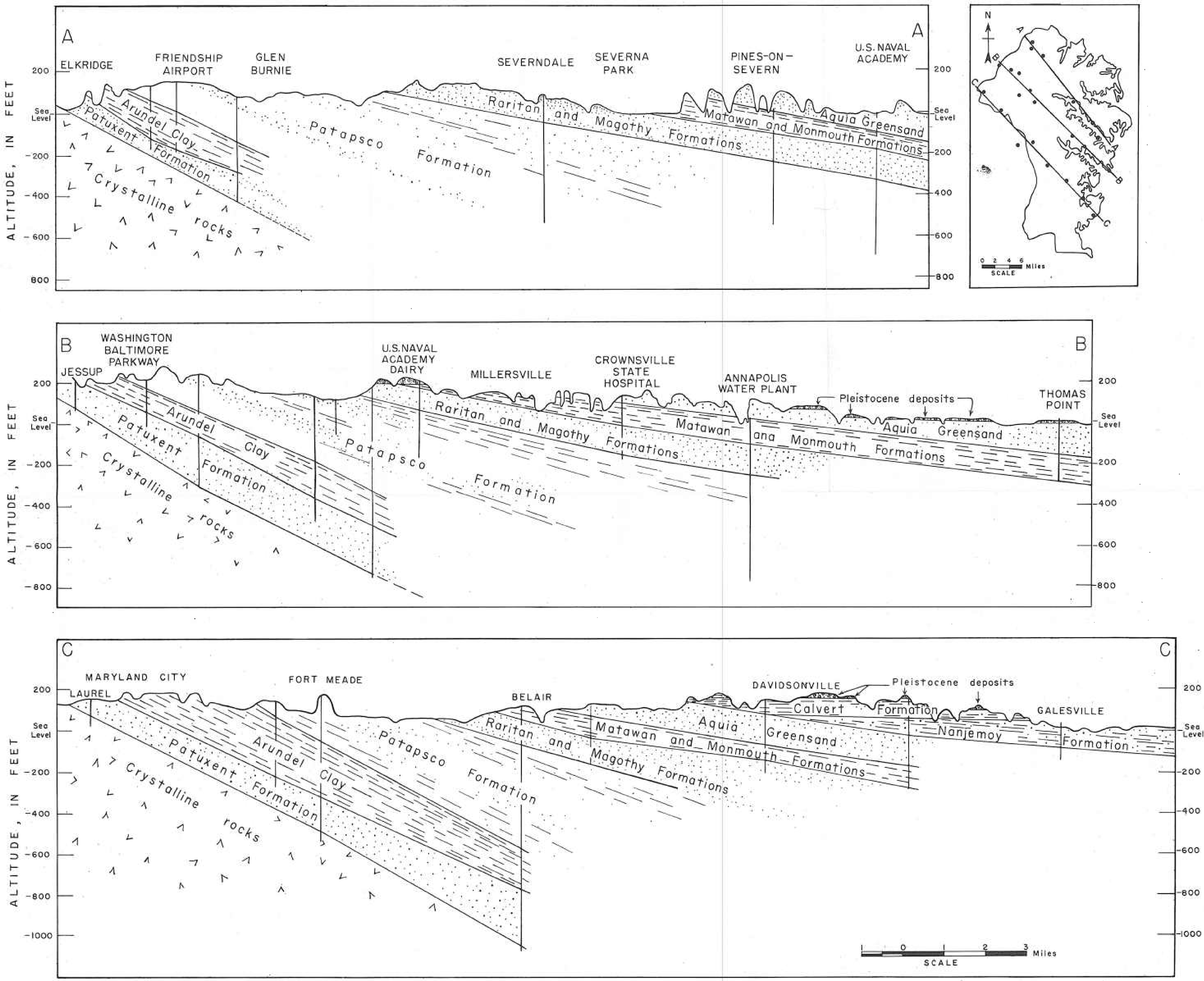
Map Showing Magnitude and Distribution of Ground-Water Pumpage in Anne Arundel County and Adjacent Areas in 1960



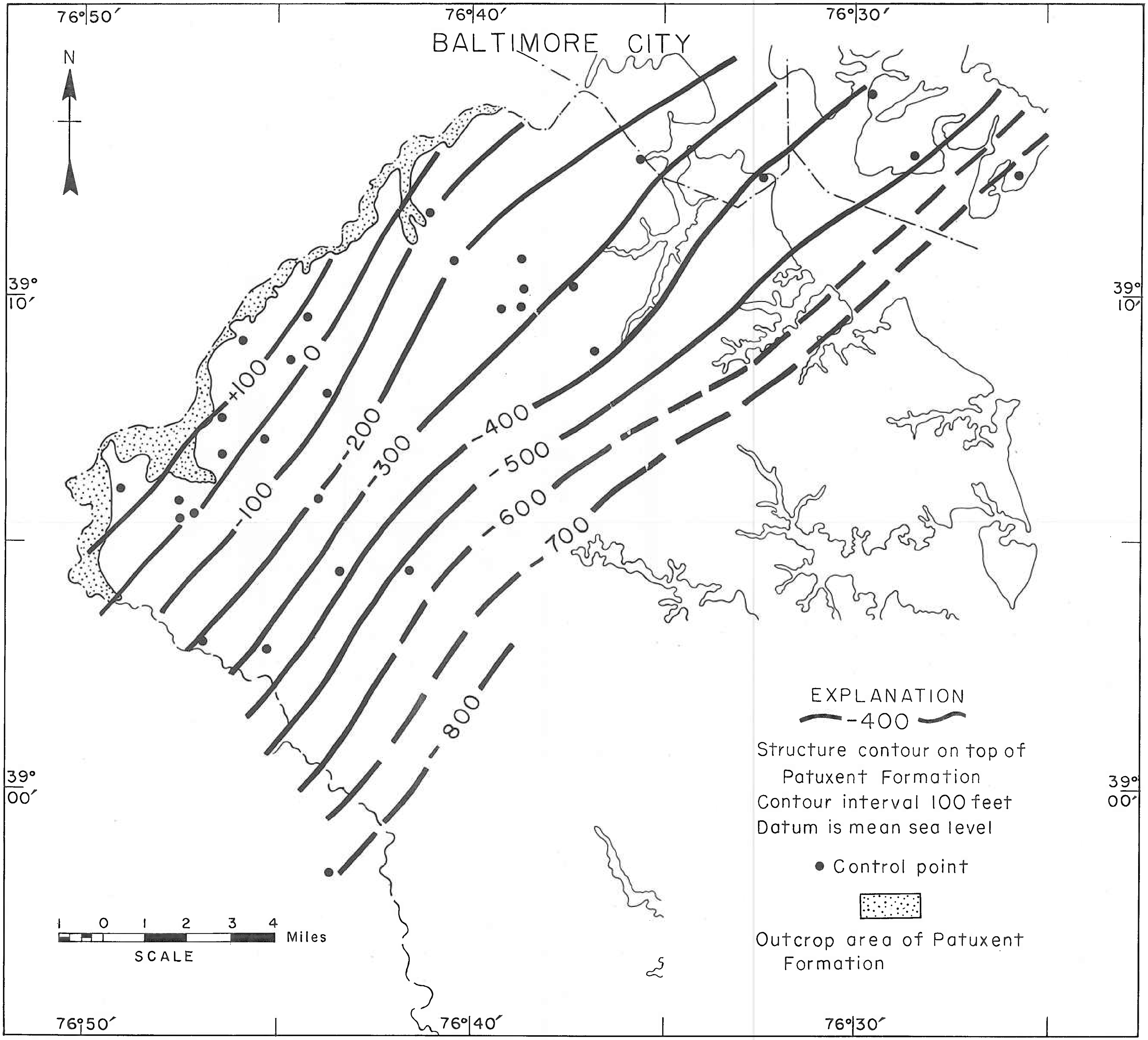
Contour Map on the Top of the Crystalline Rocks in the Northwestern Part of Anne Arundel County



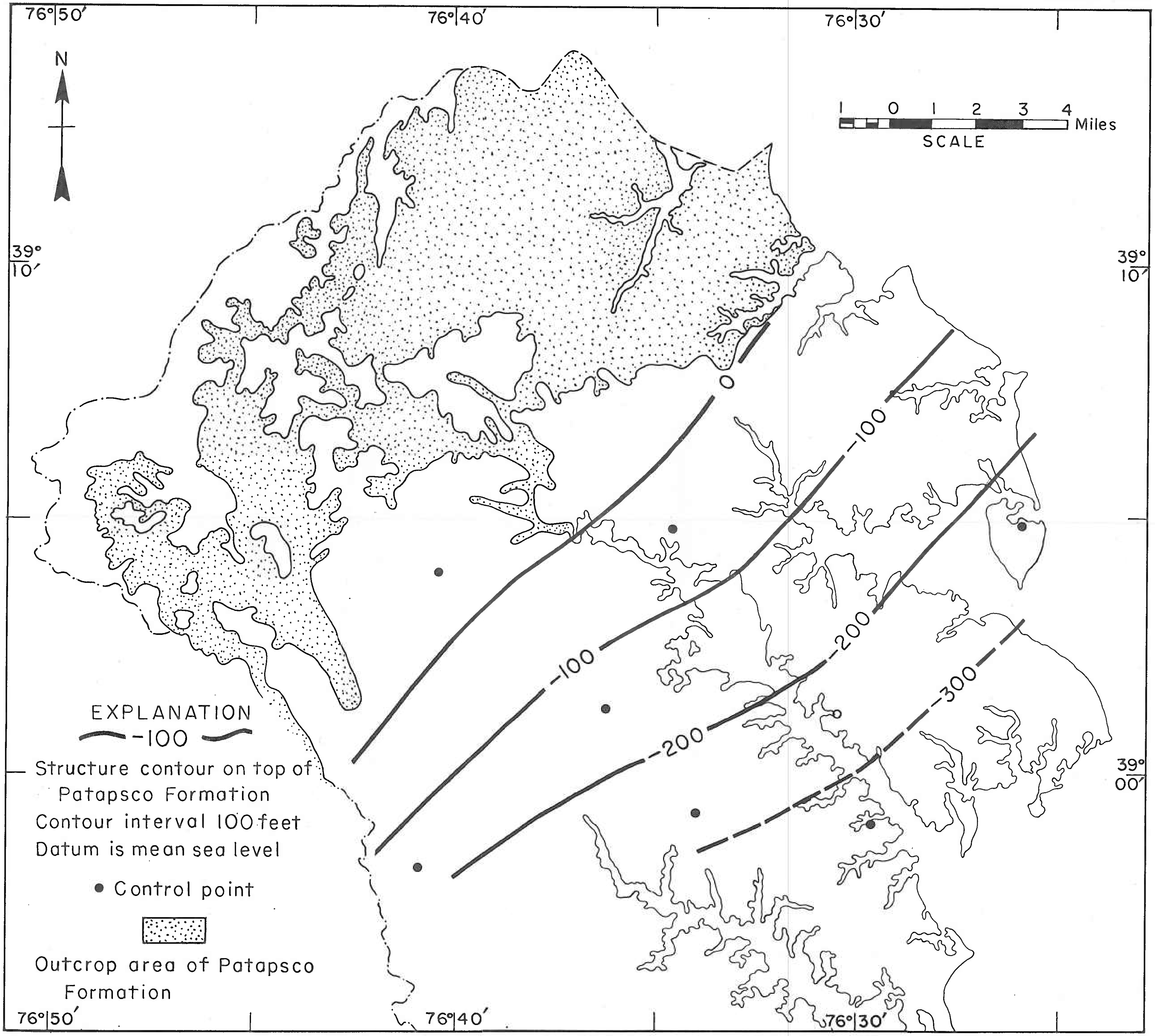
Generalized Geologic Map of Anne Arundel County



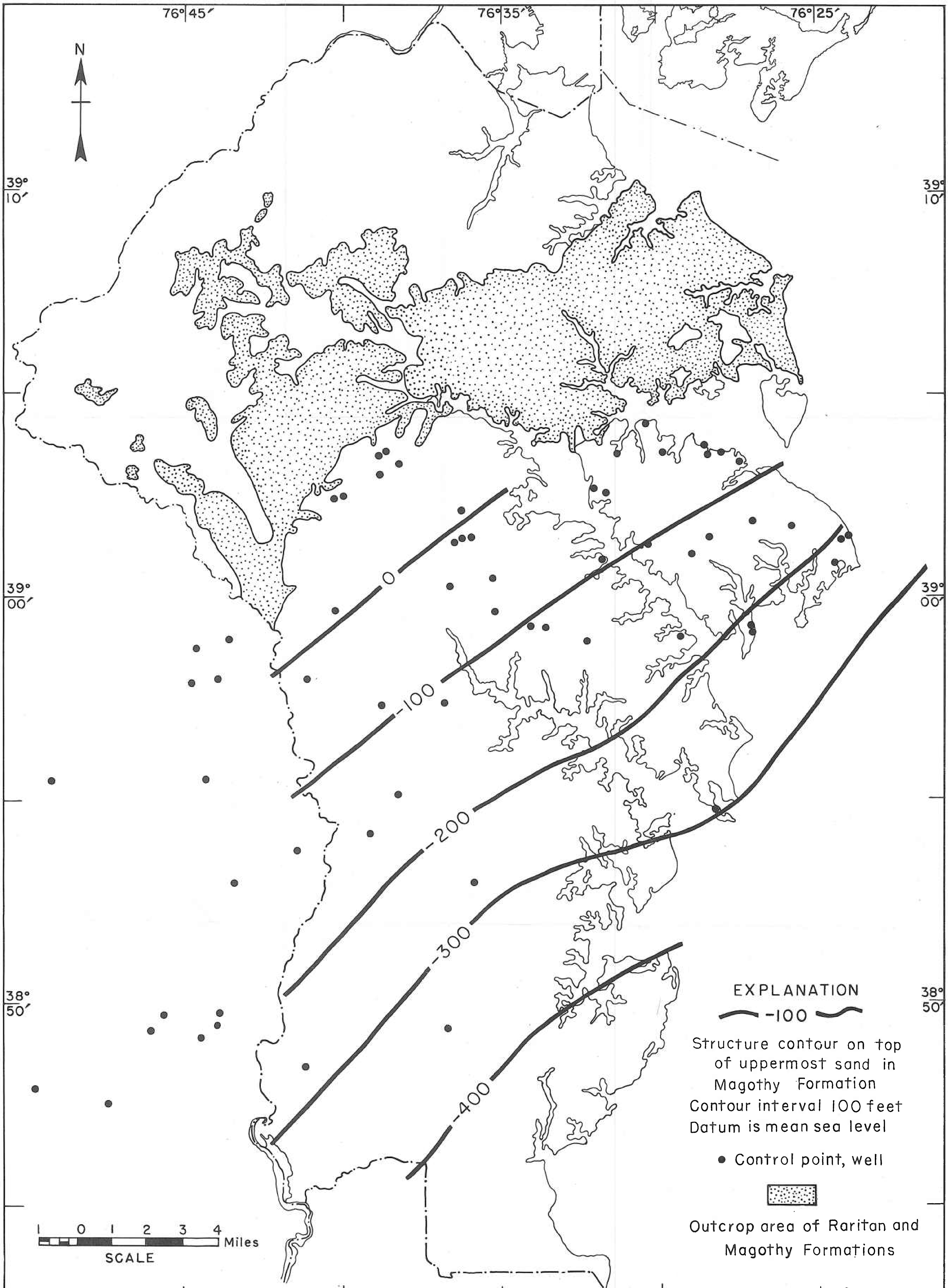
Geologic Sections A-A′, B-B′ and C-C′ Across Anne Arundel County



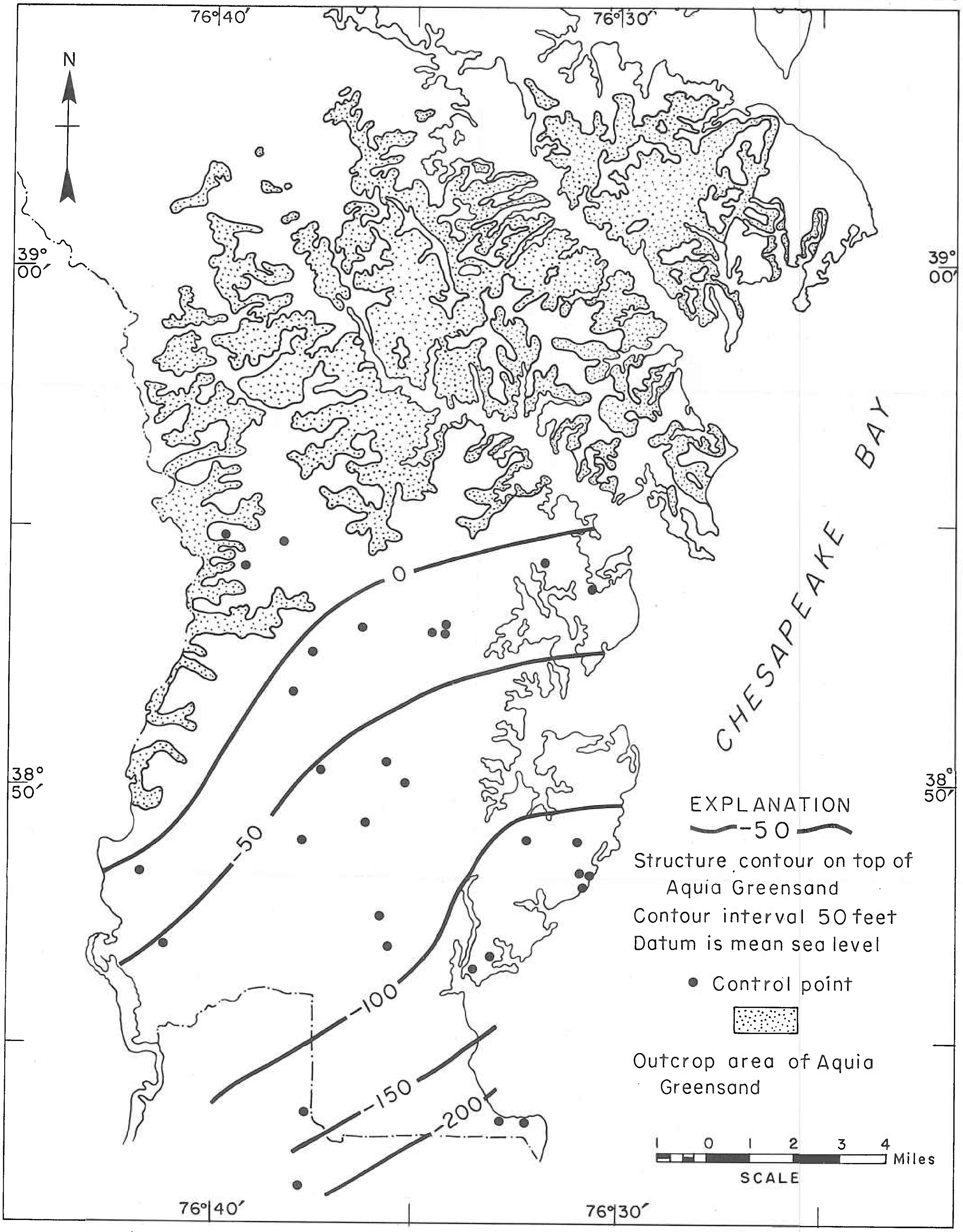
Map Showing the Outcrop Area and the Altitude of the Uppermost Water-Bearing Sand in the Patuxent Formation in Anne Arundel County



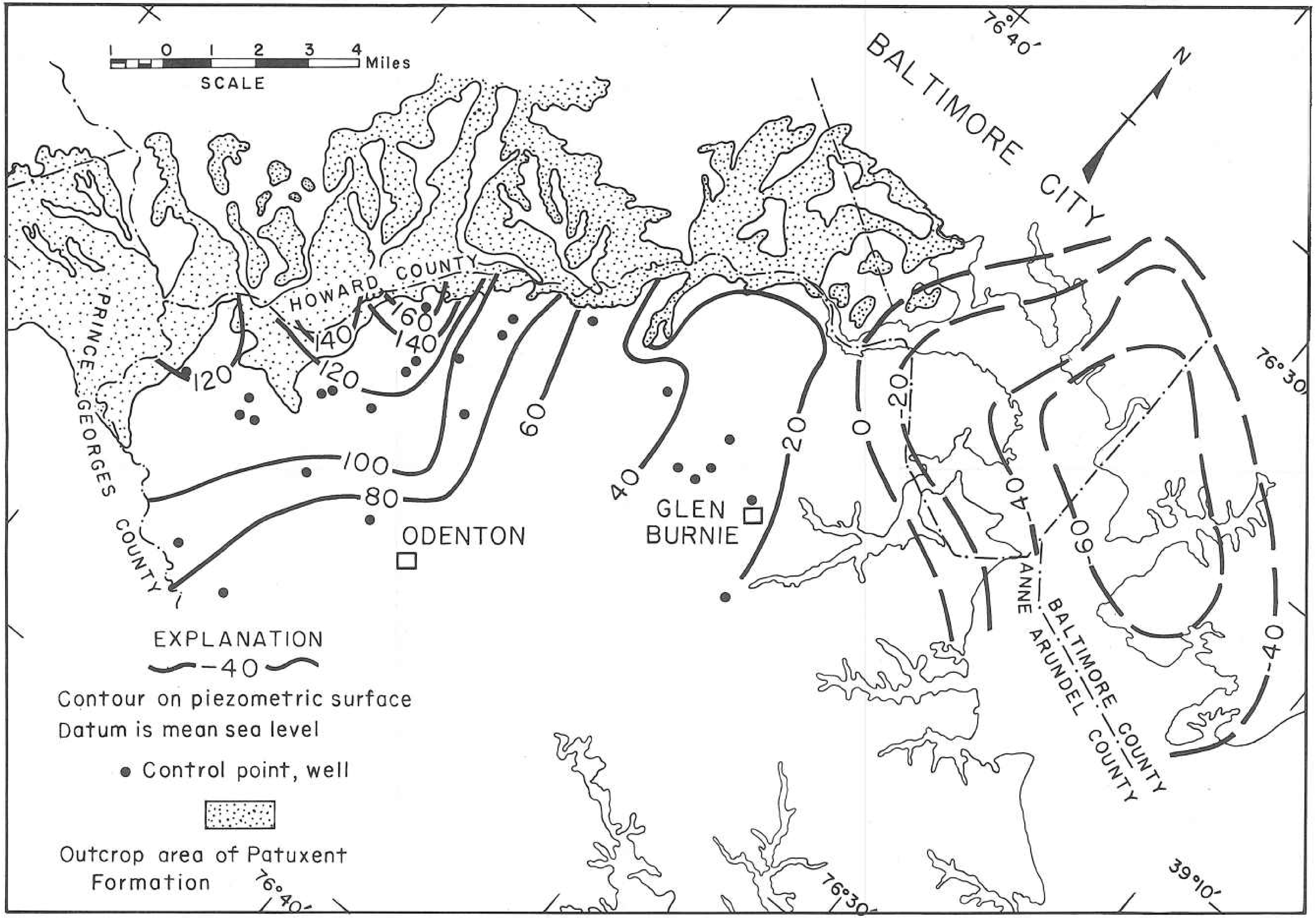
Map Showing the Outcrop Area and the Altitude of the Top of the Patapsco Formation in Anne Arundel County



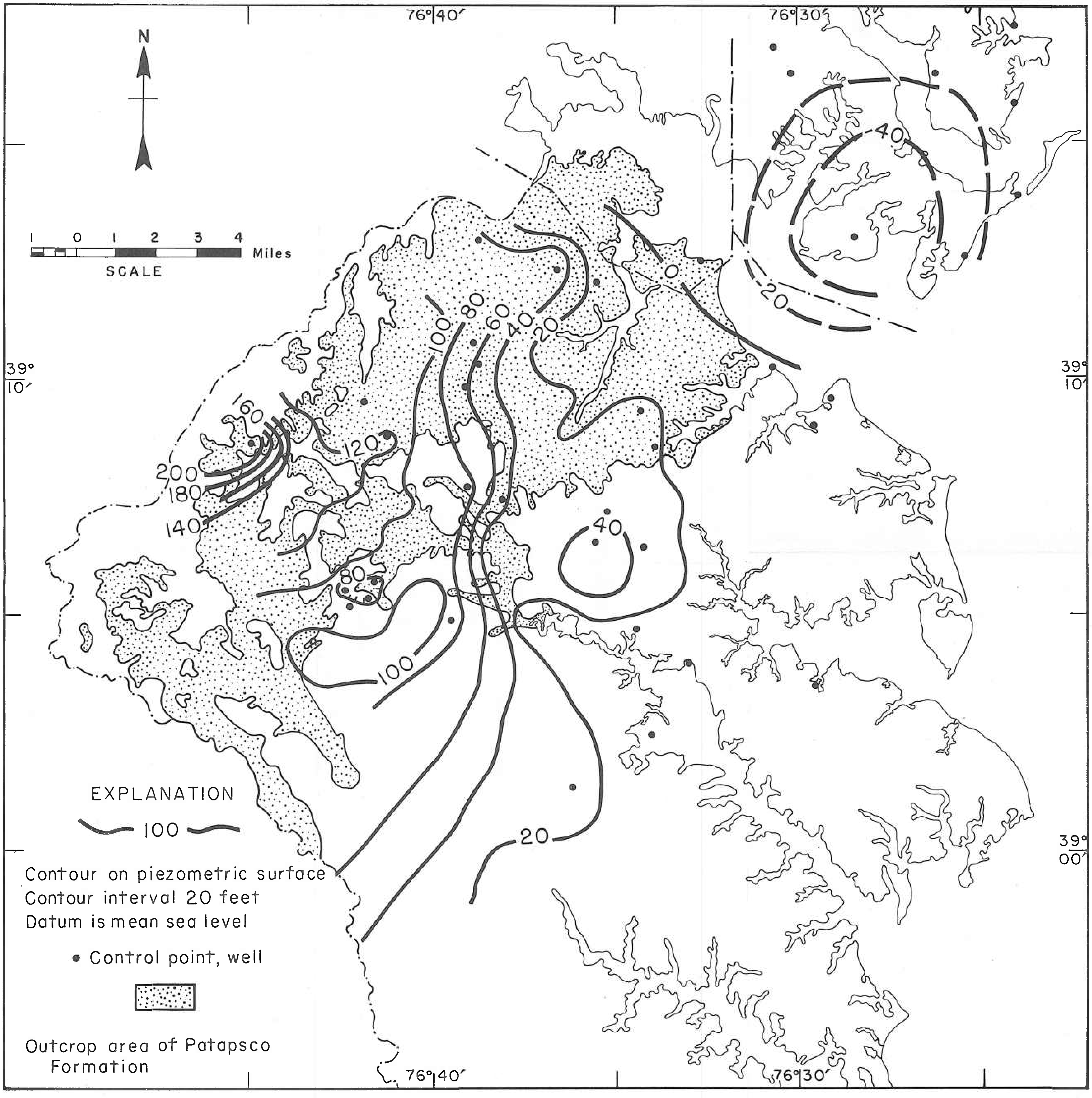
Map Showing Outcrop Area of the Magothy and Raritan Formations and the Altitude of the Top of the Magothy Formation in Anne Arundel County



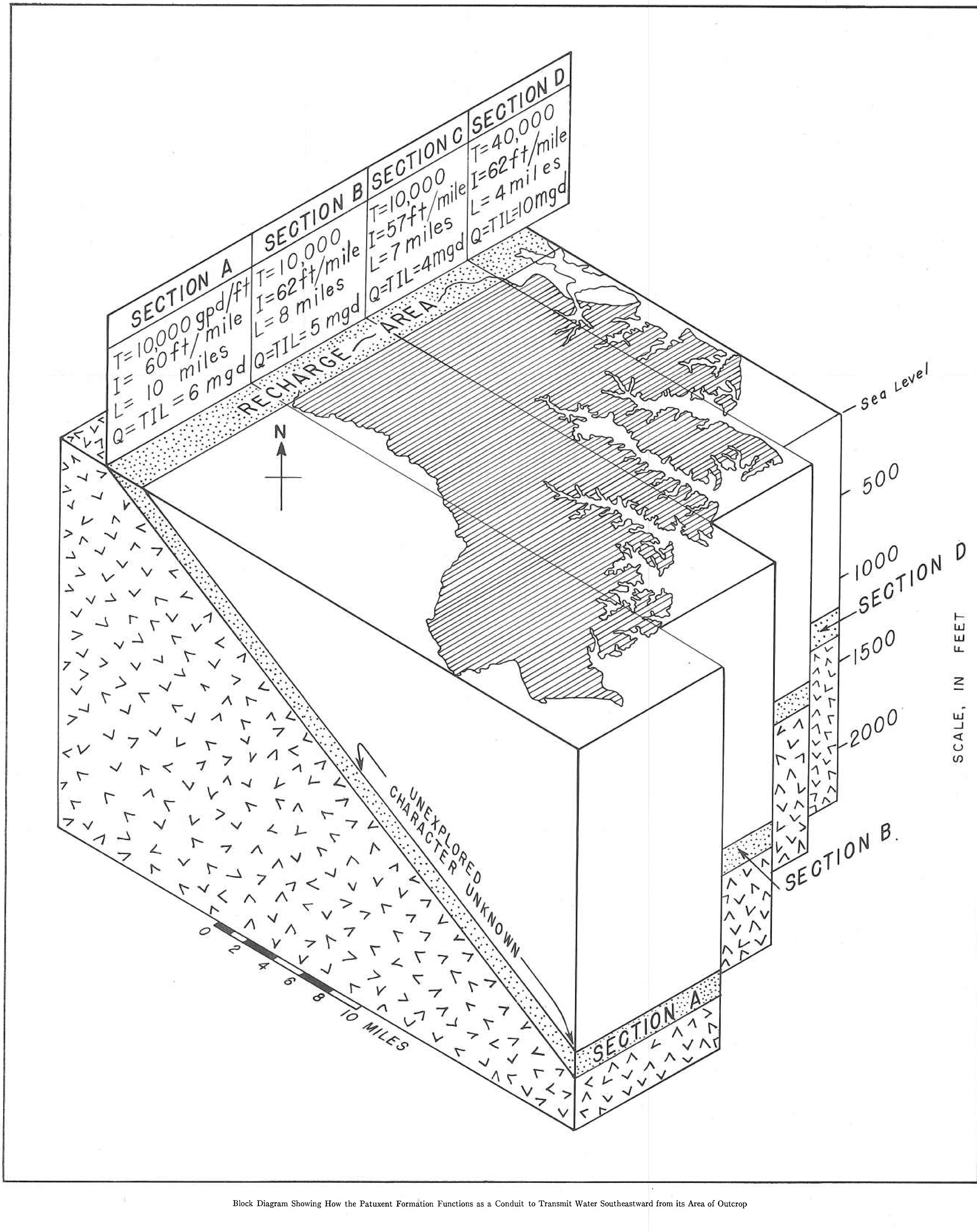
Map Showing the Outcrop Area and the Altitude of the Top of the Aquia Greensand in Anne Arundel County



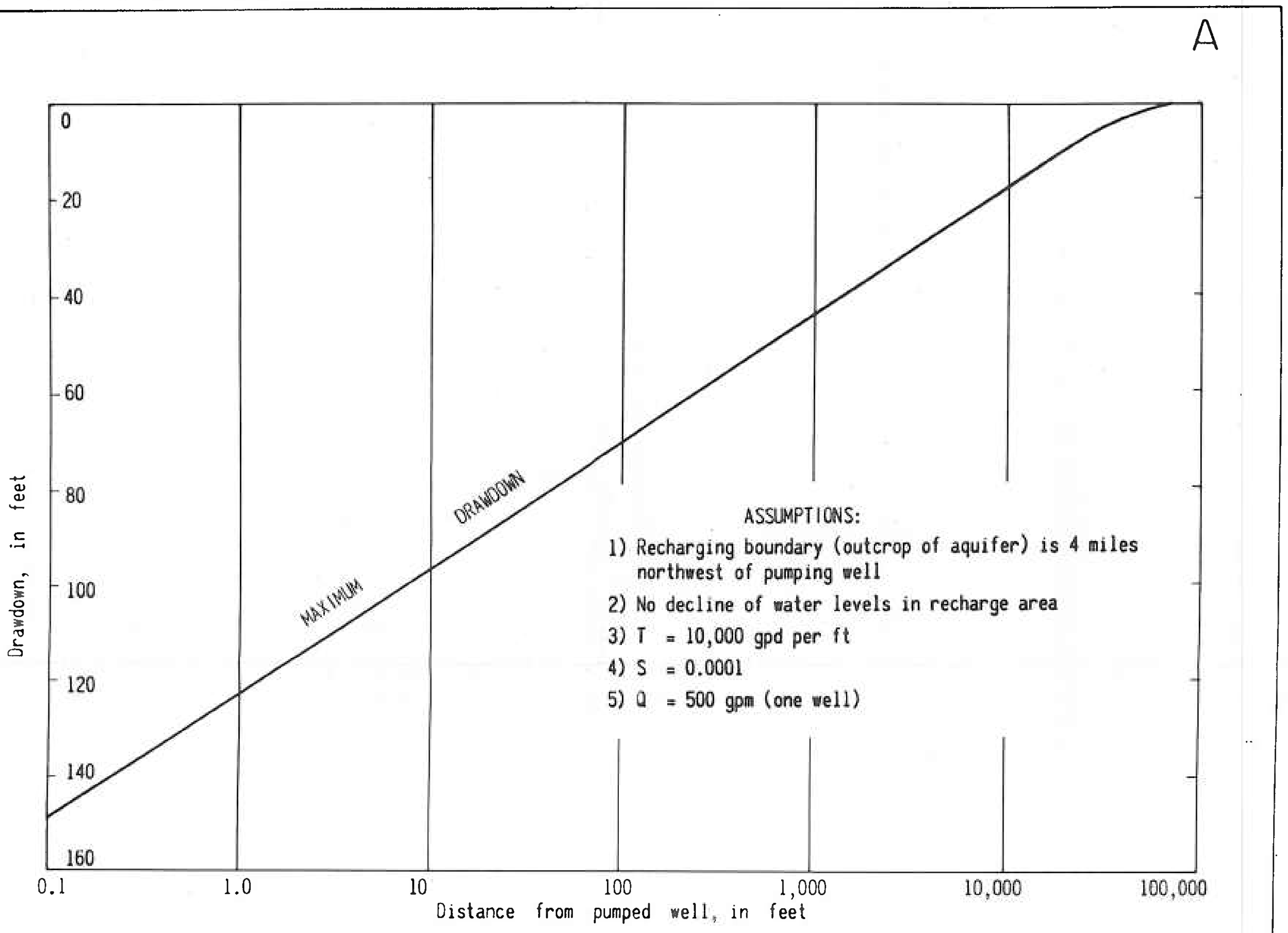
Map of the Piezometric Surface in the Patuxent Formation in Northern Anne Arundel County



Map of the Piezometric Surface in Sands in the Patapsco Formation in Anne Arundel County



Block Diagram Showing How the Patuxent Formation Functions as a Conduit to Transmit Water Southeastward from its Area of Outcrop



Graph showing the theoretical decline in water levels in the vicinity of a well discharging from a sand in the Patuxent formation at a point normal to a recharging boundary

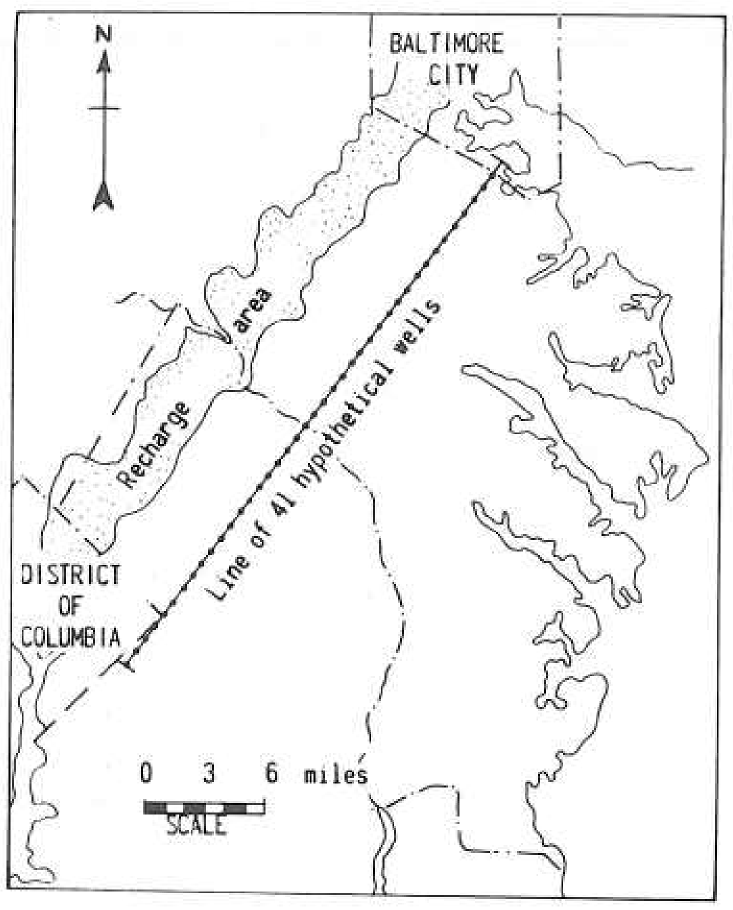
ASSUMPTIONS NECESSARY TO VALIDATE THE PREDICTED DECLINES IN WATER LEVELS SHOWN IN GRAPHS A AND B :

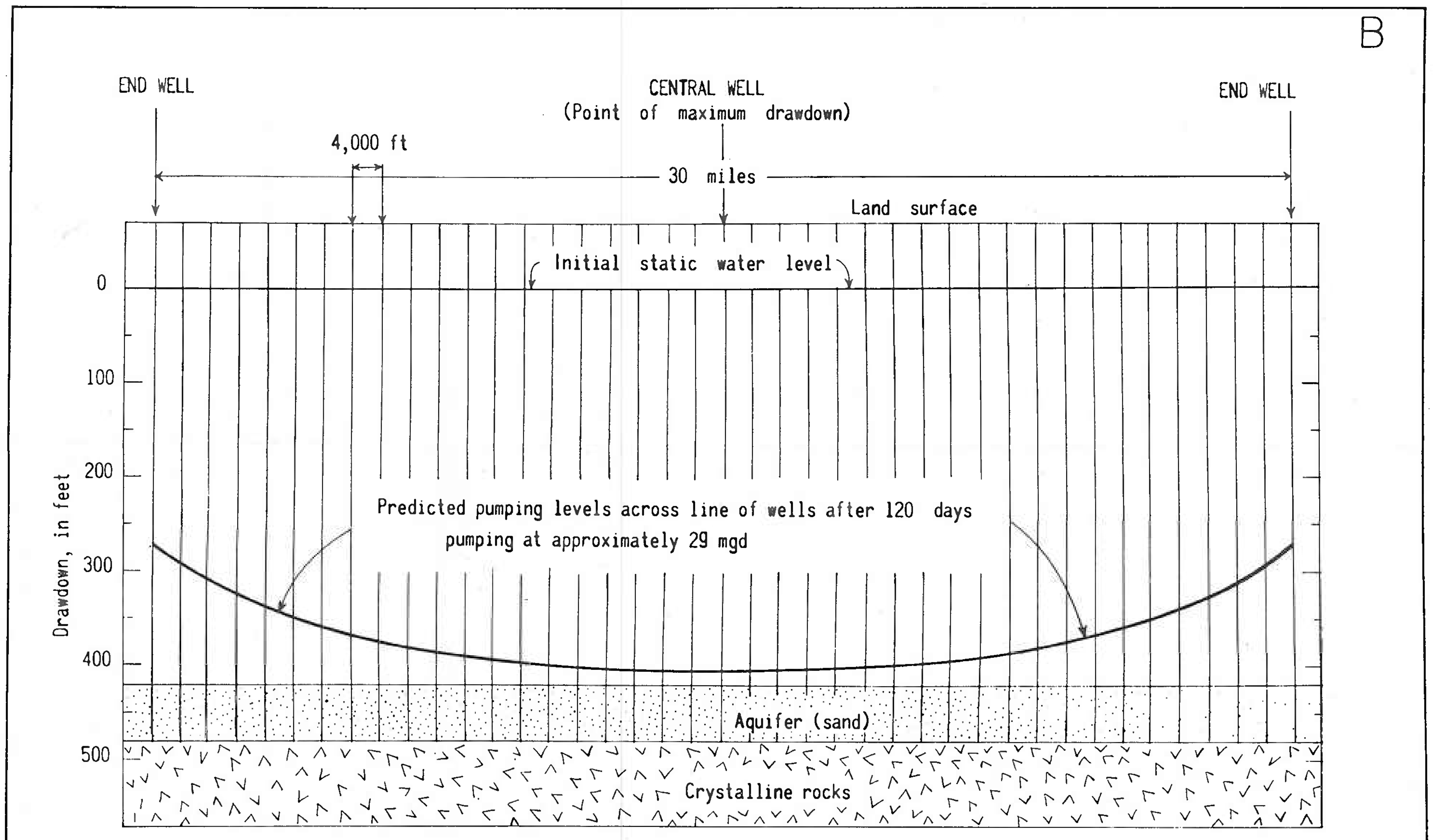
1) Line of 41 wells is parallel to recharge area traversed by perennial streams (no decline in head assumed in recharge area).
2) Aquifer is homogeneous and isotropic, and no impervious boundaries exist in it.
3) Available drawdown in each of the 41 wells is about 400 feet, or within a few feet of the top of the aquifer.
4) Wells are spaced 4,000 feet apart.
5) Aquifer is not heavily pumped in adjacent areas.
6) T = 10,000 gpd per ft
   S = 0.0001
   Q = 500 gpm (each well)

CONCLUSION BASED ON AN ANALYSIS USING THE THEIS NONEQUILIBRIUM FORMULA:

After pumping 29 mgd (20,500 gpm) for 120 days, no further decline in water levels will occur. Water level in central well will decline to a position a few feet above the top of the aquifer.

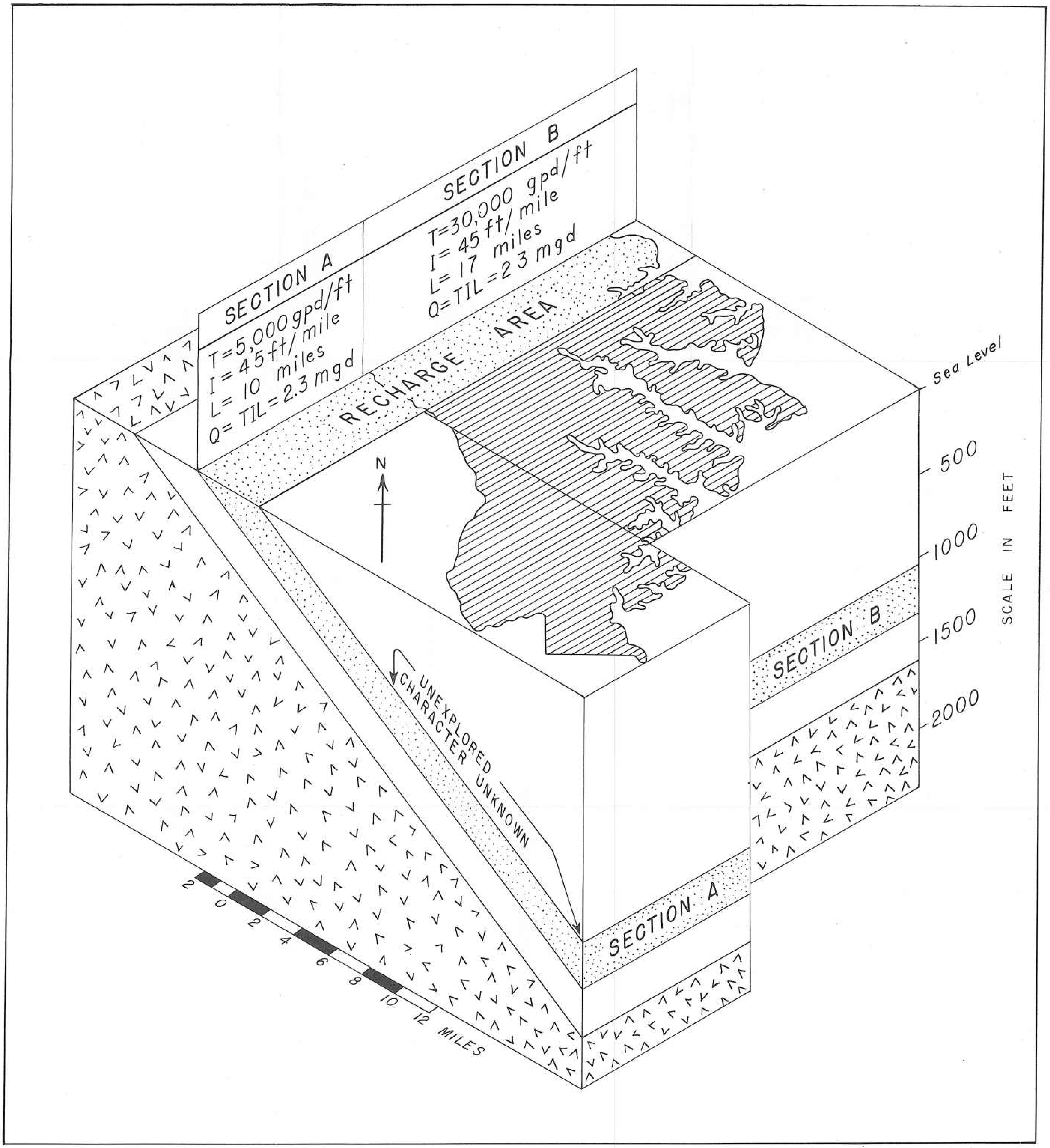
MAP SHOWING LOCATION OF LINE OF HYPOTHETICAL WELLS



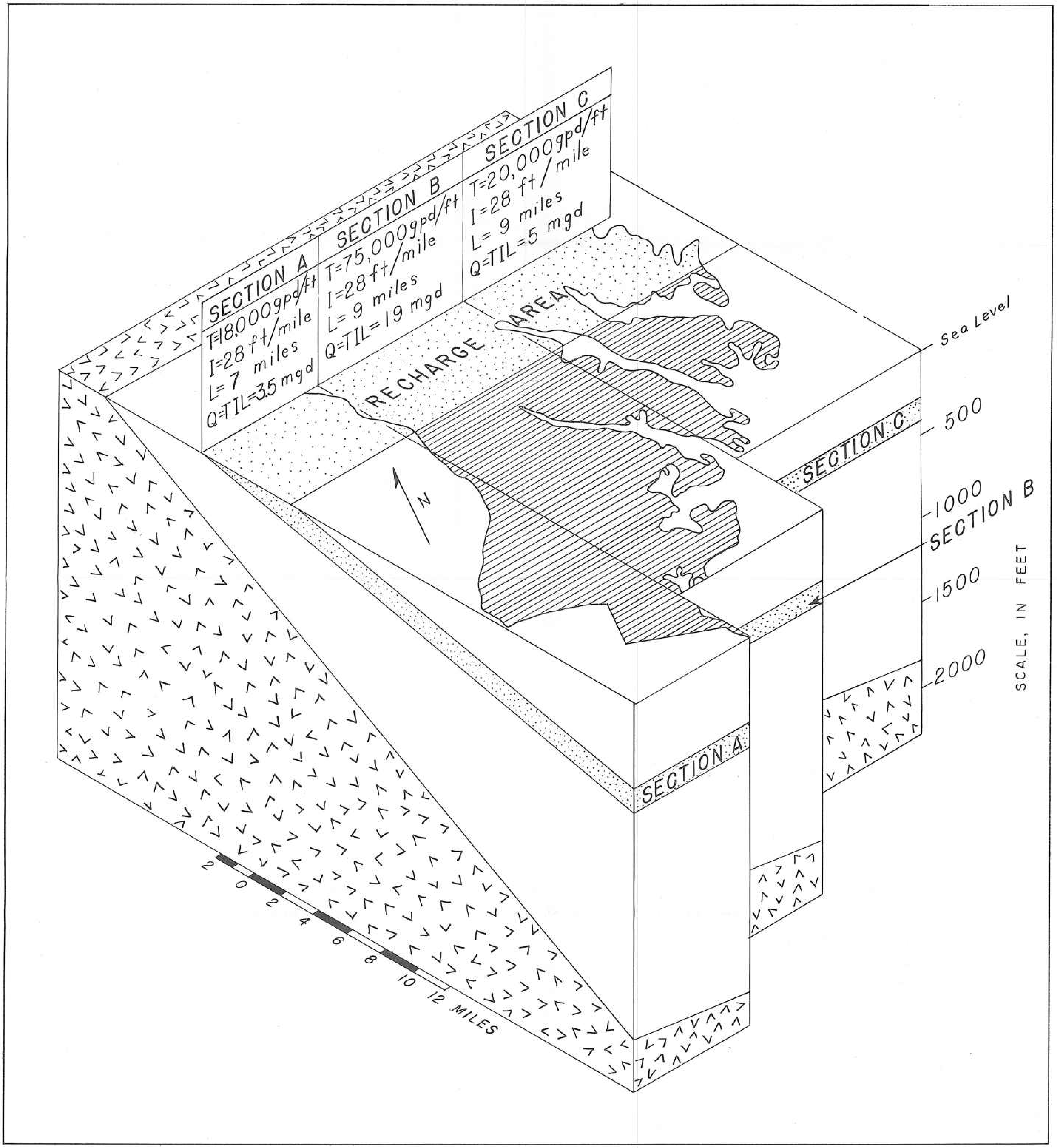


Section parallel to the strike of the aquifer showing the maximum predicted decline in water levels at each of the 41 wells shown on map C. Drawdown at each well has two components: 130 feet of decline due to its own pumping; and the decline caused by pumping each of the other 40 wells at the same rate (500 gpm)

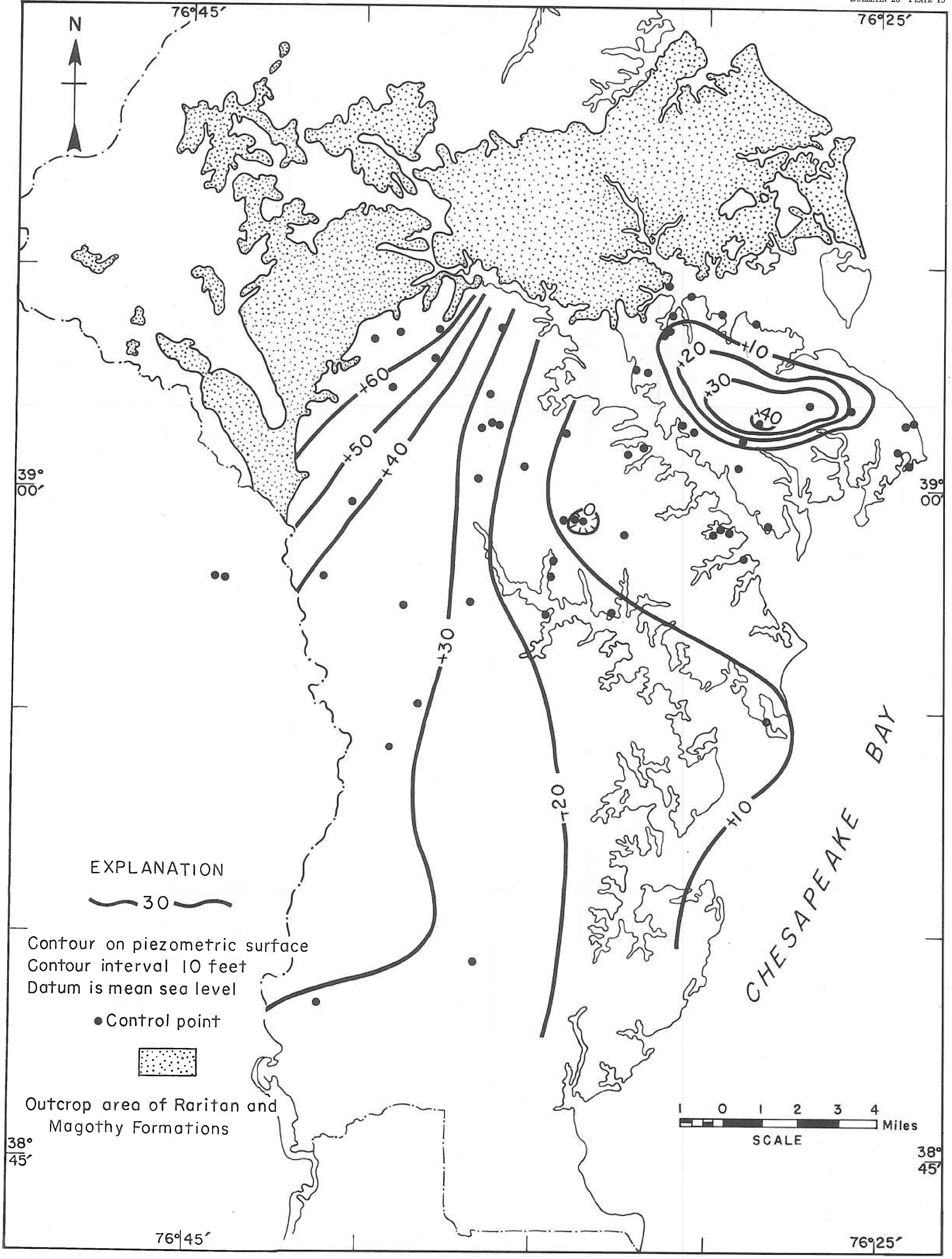
Graphs Showing Effects of Large-scale Pumping from the Patuxent Formation Along a Line Parallel to the Outcrop Area



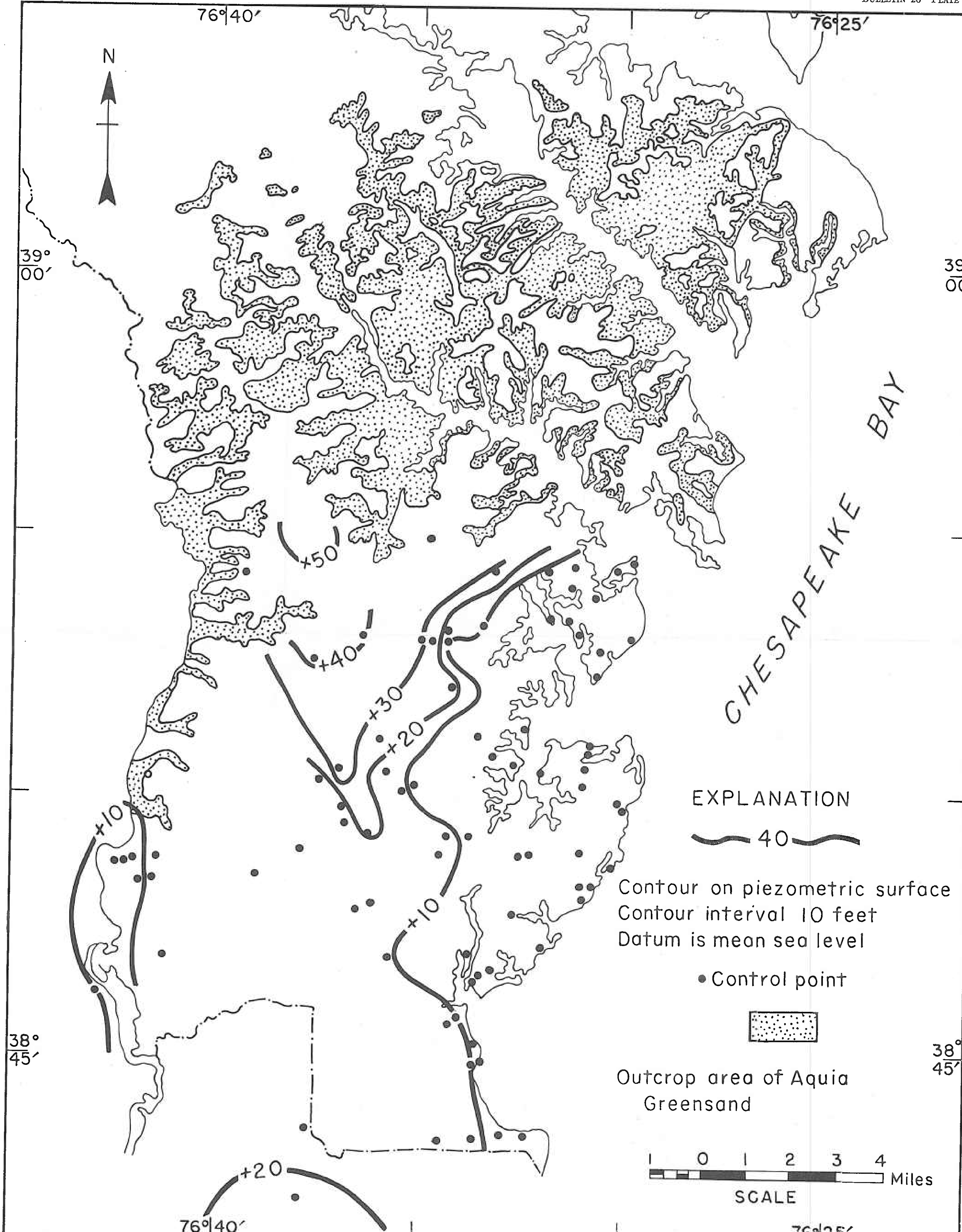
Block Diagram Showing How the Patapsco Formation Functions as a Conduit to Transmit Water Southeastward from its Area of Outcrop



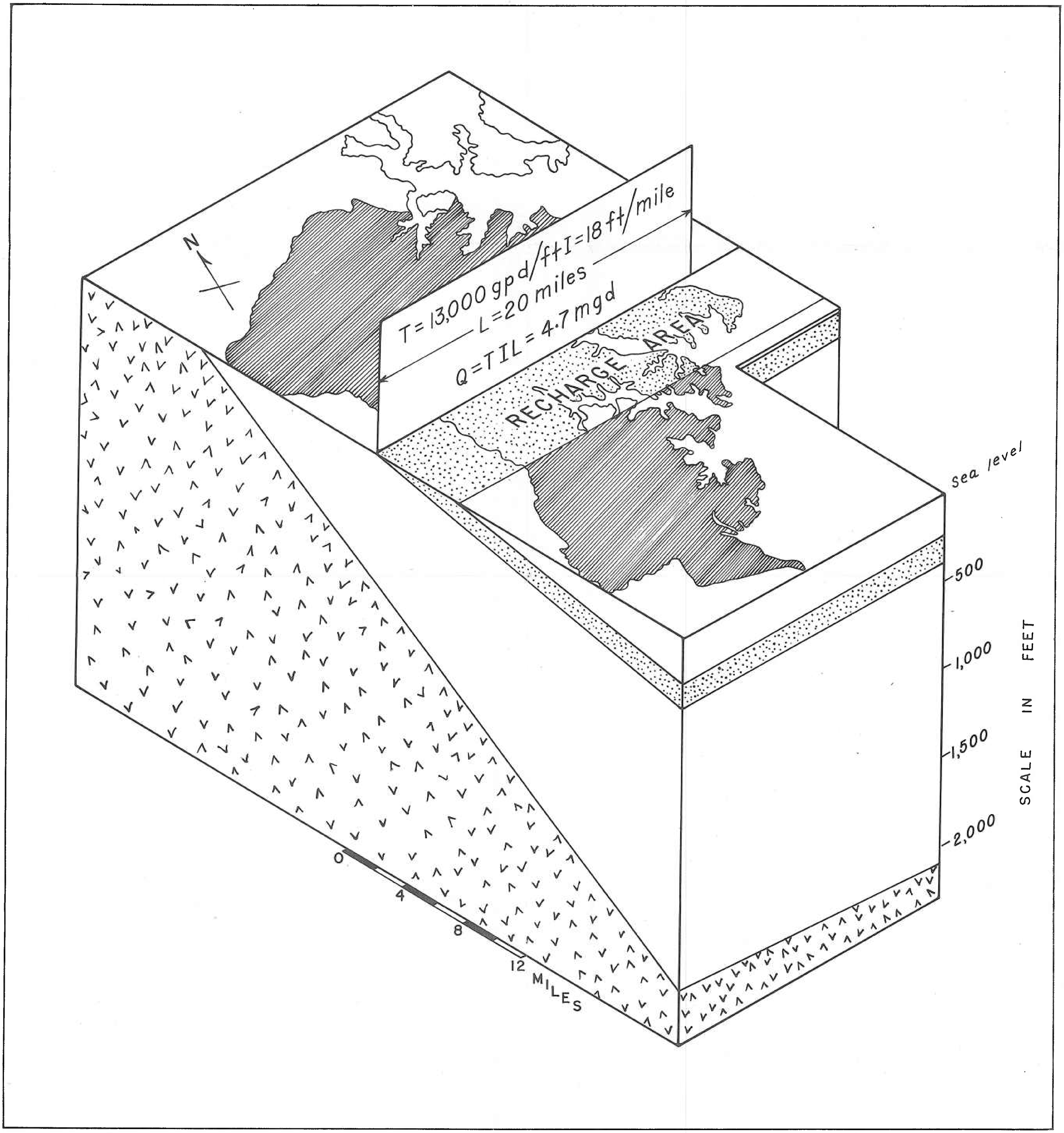
Block Diagram Showing How the Raritan and Magothy Formations Function as a Conduit to Transmit Water Southeastward from Their Area of Outcrop



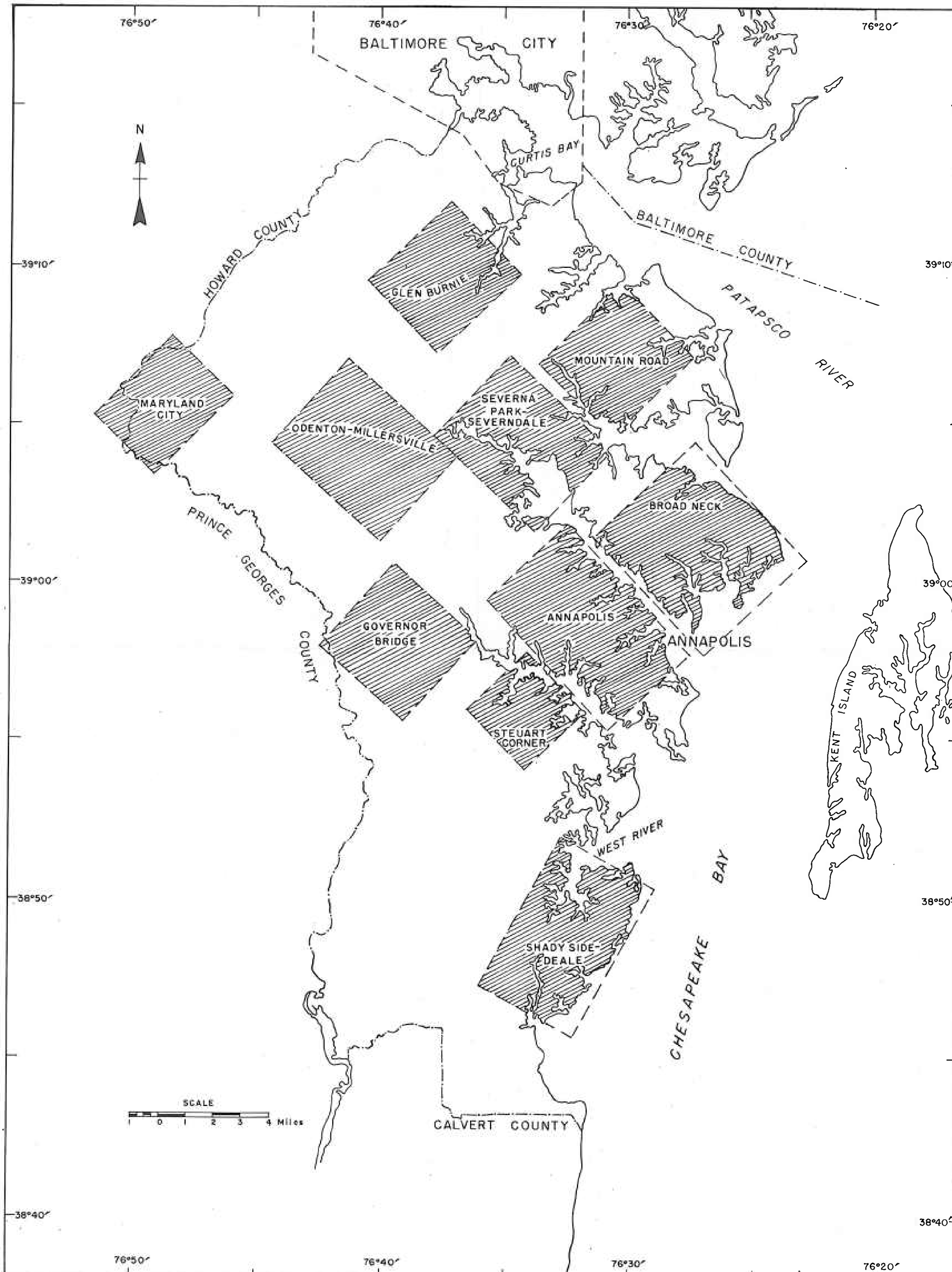
Map of the Piezometric Surface in the Uppermost Sands in the Raritan and Magothy Formations



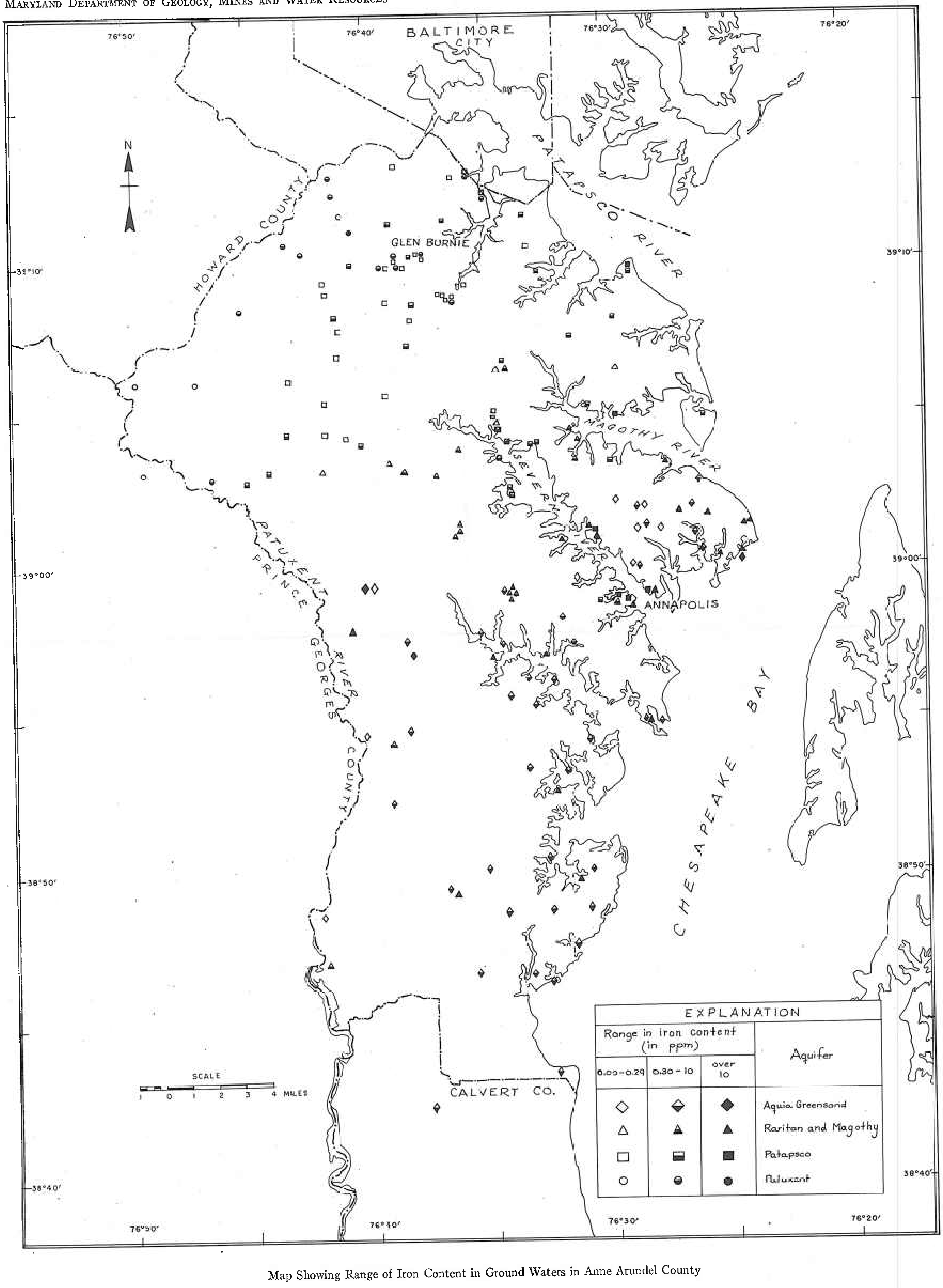
Map of the Piezometric Surface in the Aquia Greensand in Anne Arundel County



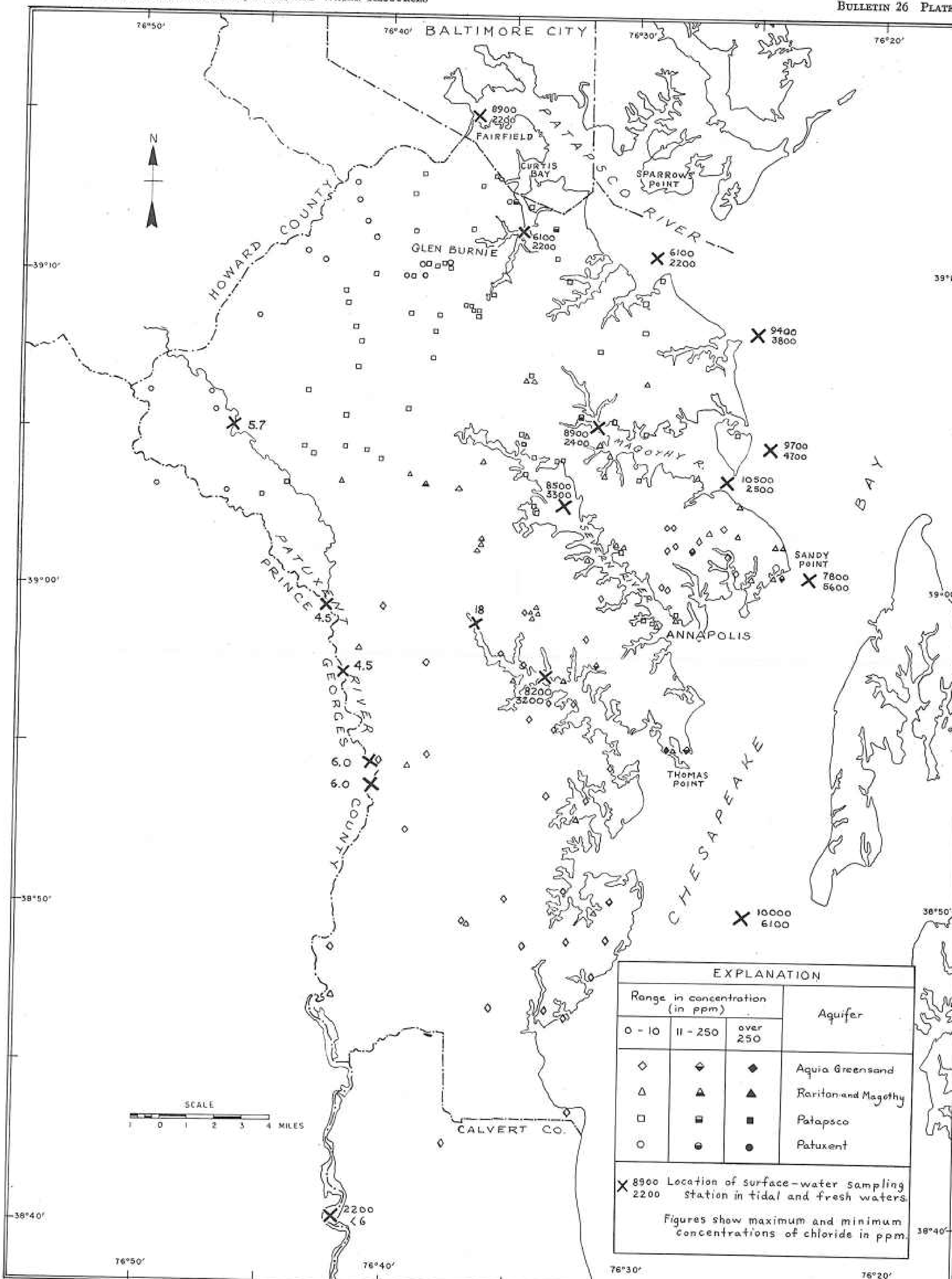
Block Diagram Showing How the Aquia Greensand Functions as a Conduit to Transmit Water Downdip from its Recharge Area



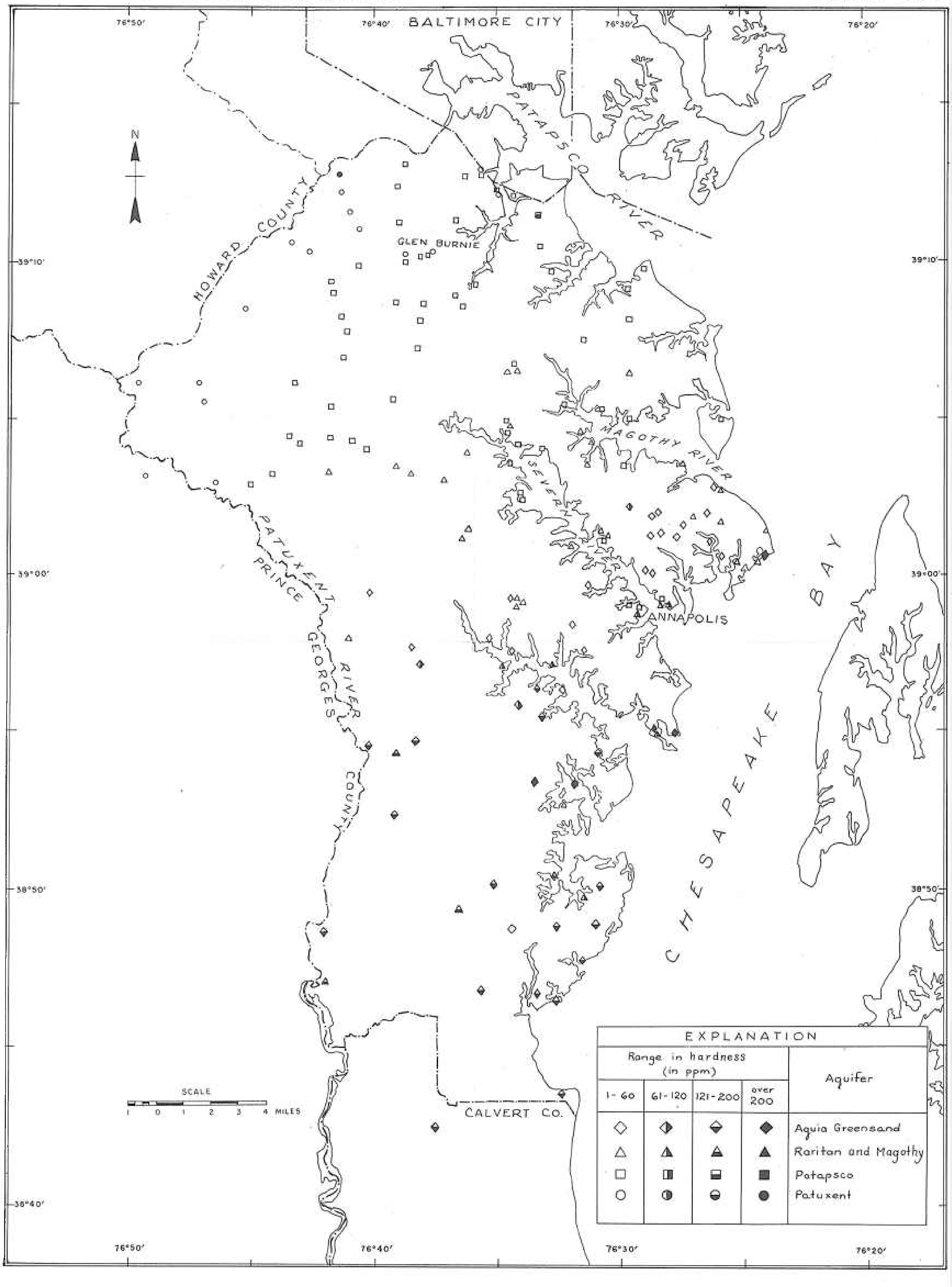
Map Showing Areas of Special Interest in the Ground-Water Investigation of Anne Arundel County



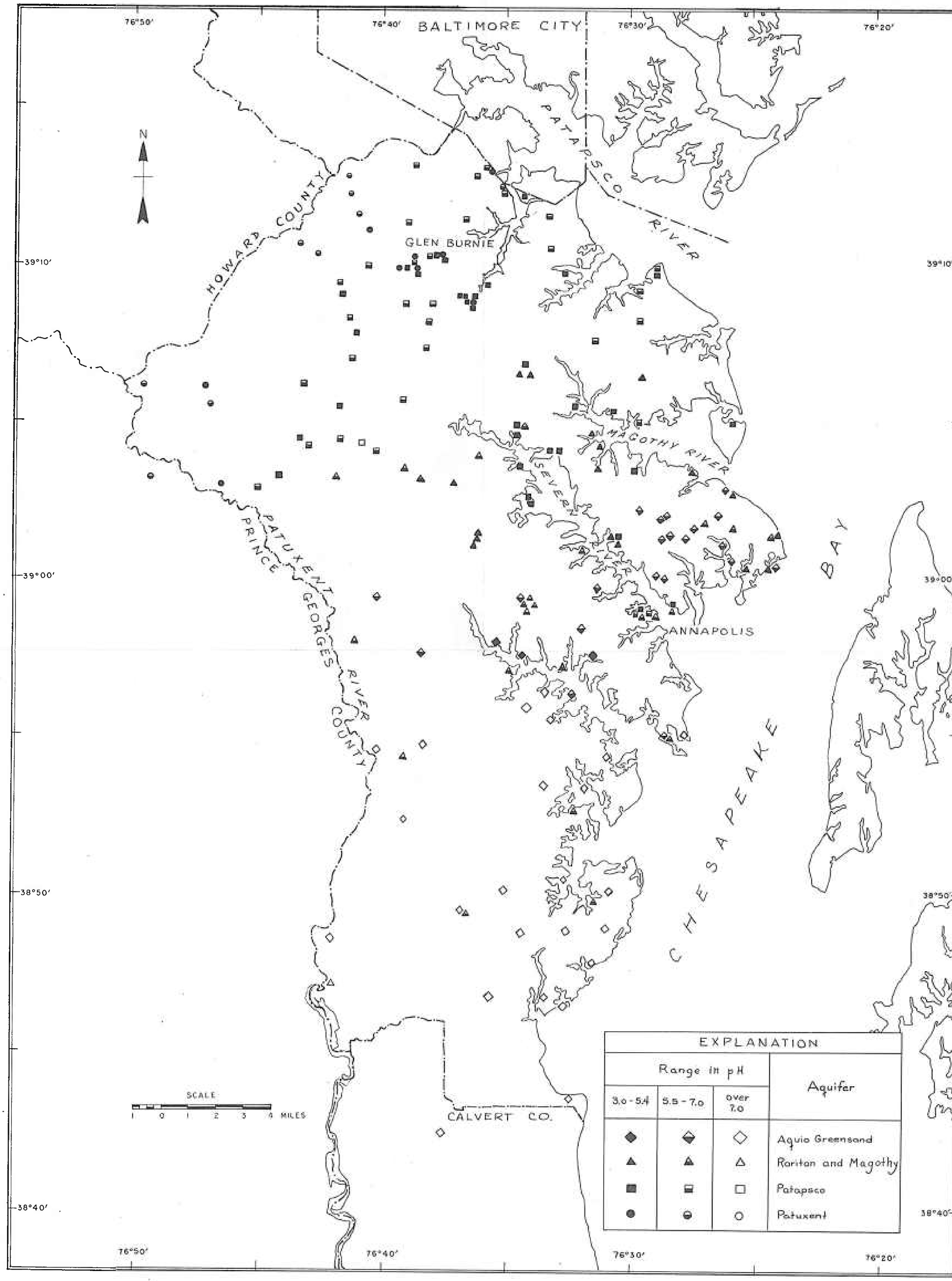
Map Showing Range of Iron Content in Ground Waters in Anne Arundel County



Map Showing Range of Chloride Content in Ground Waters and Surface Waters in Anne Arundel County



Map Showing Range in Hardness of Ground Waters in Anne Arundel County



Map Showing Range in pH of Ground Waters in Anne Arundel County